45C ROBOTICS

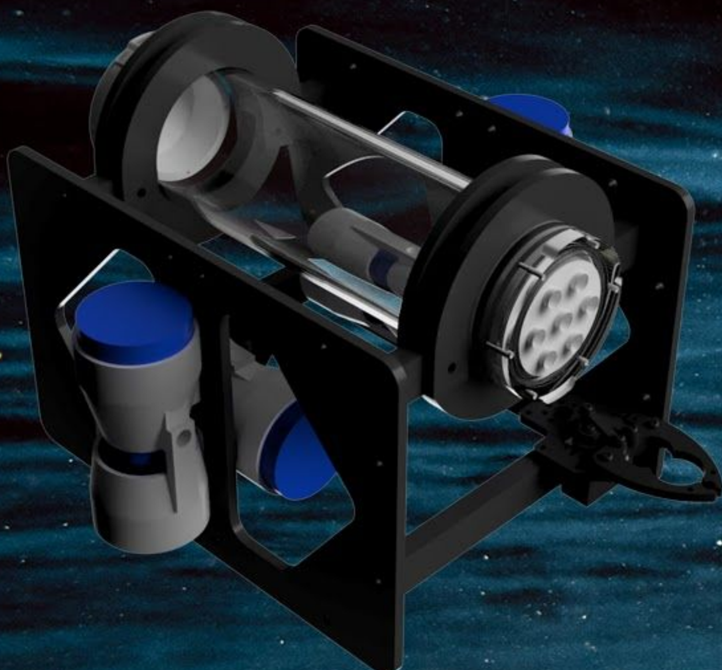
CAMS ROV ROBOTICS TEAM

TRITON VII

California Academy of Mathematics and Science

Carson, California

MATE 2018



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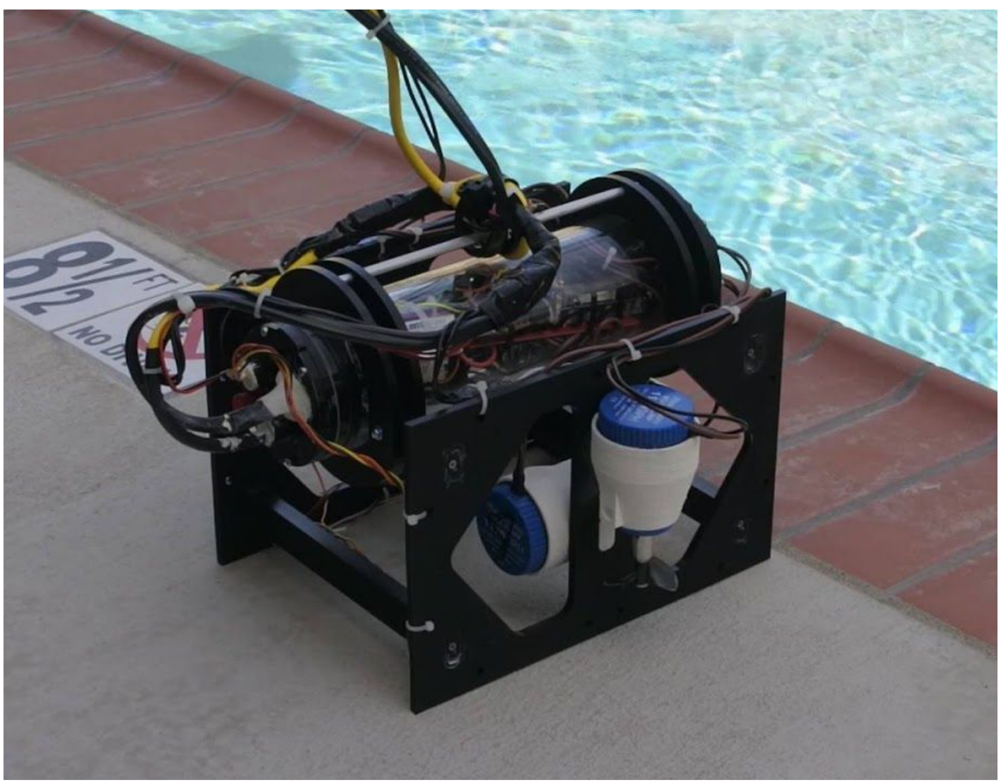
Abstract

Triton VII (fig 1) is the newest Remotely Operated Vehicle (ROV) from the 45C Robotics team, optimized for maximum underwater maneuverability, efficiency, and cost-effectiveness. The robot is designed to (1) locate the wreckage of a vintage aircraft and return its engine to the surface, (2) install an ocean based seismometer (OBS), and (3) install a tidal turbine and instrumentation to monitor the environment. To accomplish these tasks, our ROV is equipped with two claws—one directed forward and another directed downward—along with a piezo buzzer to activate the acoustic sensor within the OBS to release it from the weight.

45C Robotics is from the California Academy of Mathematics and Science (CAMS) located in Carson, California. We began our endeavour into the MATE ROV Ranger competition as an independent club for the first time last year, and have worked diligently to overcome the minimal support provided from our school. 45C Robotics has eight team members, each specialized in a particular field, in order to challenge the limits of what an ROV can be. Our team has pushed through difficulties with a positive team culture for nine months to create an ROV that lives up to the Triton name.

Figure 1: Triton VII during construction



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Theme Significance

The objectives for this year's competition include aircraft recovery, earthquake detection, and energy generation. The applied physics laboratory at the University of Washington is currently requesting proposals for an ROV that can operate in the Pacific Northwest in both salt and freshwater. This ROV needs to be able to locate an underwater aircraft wreckage, install/recover a seismometer, and install a tidal turbine to monitor the aquatic environment.

In the Pacific Northwest—more specifically at the northwest part of Lake Washington—is the Sand Point Naval Air Station. This air station has seen many takeoffs, and almost all of them have been recorded. However, recent information has shown that a series of test flights conducted were not all successful. Presumably, many of these planes crashed due to pilot or system error, and are currently at the bottom of Lake Washington. ROVs are needed to search, find, and identify these lost planes, because these planes represent a part of history, and their contents can only be of use if they are recovered and placed in museums.

The Cascadia subduction zone consists of a tectonic plate that stretches from Vancouver to the northern part of California. Processes in this zone include active volcanism and deep earthquakes. These have the potential to be very harmful to us, as seen in the volcanic eruption of Mount St. Helen, which killed over 50 people. This plate also has the potential to cause an earthquake that can reach up to a 9.0 on the richter scale. Researchers are pushing to install a series of OBS's in the ocean to monitor the seismic activity, so that we are better prepared and do not experience the same casualties caused by the volcanic eruption of Mount St. Helen. In order to do this, ROVs must be sent under water to retrieve the OBS's. The ROV's operation will also include disconnecting the OBS's from their respective power sources, and bringing them up to the surface.

Washington State and other government agencies are currently researching the use of underwater turbines as a potential energy source. Many different devices need to be installed in order to see if turbines are viable. These devices include an I-AMP and a ADV. The I-AMP will be installed in order to measure the tidal velocities and the environmental impact of the turbines. The ADV will be installed in order to monitor to water velocities, so that this data could be compared with the I-AMPs. Finally the ROV will also need to recover and transport eel grass samples for analysis and to replenish any areas that were disturbed the turbines.

Figure 2: Washington Lake

Company History

45C Robotics is a rising competitor in the MATE ROV competition. While the California Academy of Mathematics and Science (CAMS) ROV team operated as an elective course in previous years, last year we branched off as an individual robotics club. By becoming a separate entity from the school, as opposed to a required class, we became comprised of only the most passionate engineers, marketers, and programmers to ensure success (Figure 3). Although the CAMS ROV teams had continually placed nearly last at regionals every year, the 45C Robotics team not only advanced from the regional competition, but also ranked 16th out of 40 competitors in the 2017 MATE international competition within the first year of operation.

Moreover, we were awarded the safety consciousness award for our stellar safety measures, including a safety checklist that was followed before any procedure. Alongside 45C's rapid growth, we have experimented with numerous organizational structures, and are currently using the most effective system we've found. 45C Robotics utilizes a flat company structure to minimize bureaucracy and maximize efficiency. We have a Chief Executive Officer (CEO) and a leader in each subsection (e.g. Electrical, Mechanical, Programming, Finance, and Machining) to keep all team members focused and generally informed through the chain of command.

Instead of designating specific tasks for every team member, each person decides his or her own projects to work on and enlists the help of peers accordingly. Each subteam works independently, but retains close communication with the leaders and the rest of the members. This gives team members the opportunity to receive feedback without leadership micromanaging details. Each sub-leader takes charge of specific area of communication and development (e.g. creating a parts list, finding sponsor contacts, etc.) and helps guide each sub-team to complete major tasks (e.g. designing and fabricating the control box) in an organized and timely manner. This organizational structure promotes productivity by creating a safe space for the blooming of ideas assisted by constructive criticism, which has allowed us to create an efficient robot.

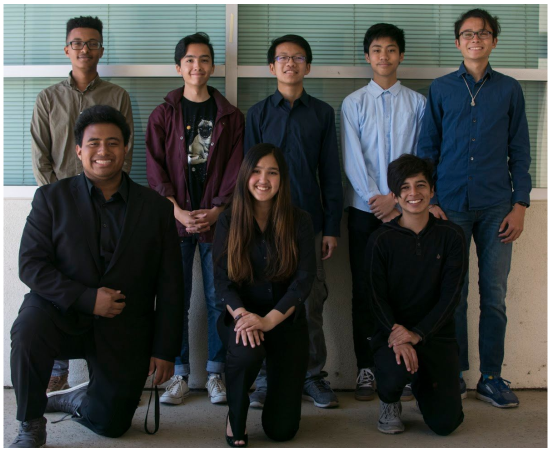


Figure 3: 45C Robotics Team Picture

Left to right, top to bottom
Isaac Addis '19 - Programing Lead
Marcelo Cubillos '19 - Machining Lead
Jiajer Ho '19 - CEO and Electrical Lead
Brad Biscocho' 19 - Mechanical Lead
Etisone Escamilla' 18 - Mechanical Engineer
Celia Yu' 19 - Mech Co-lead
Victor Zuleta' 20 - Programmer

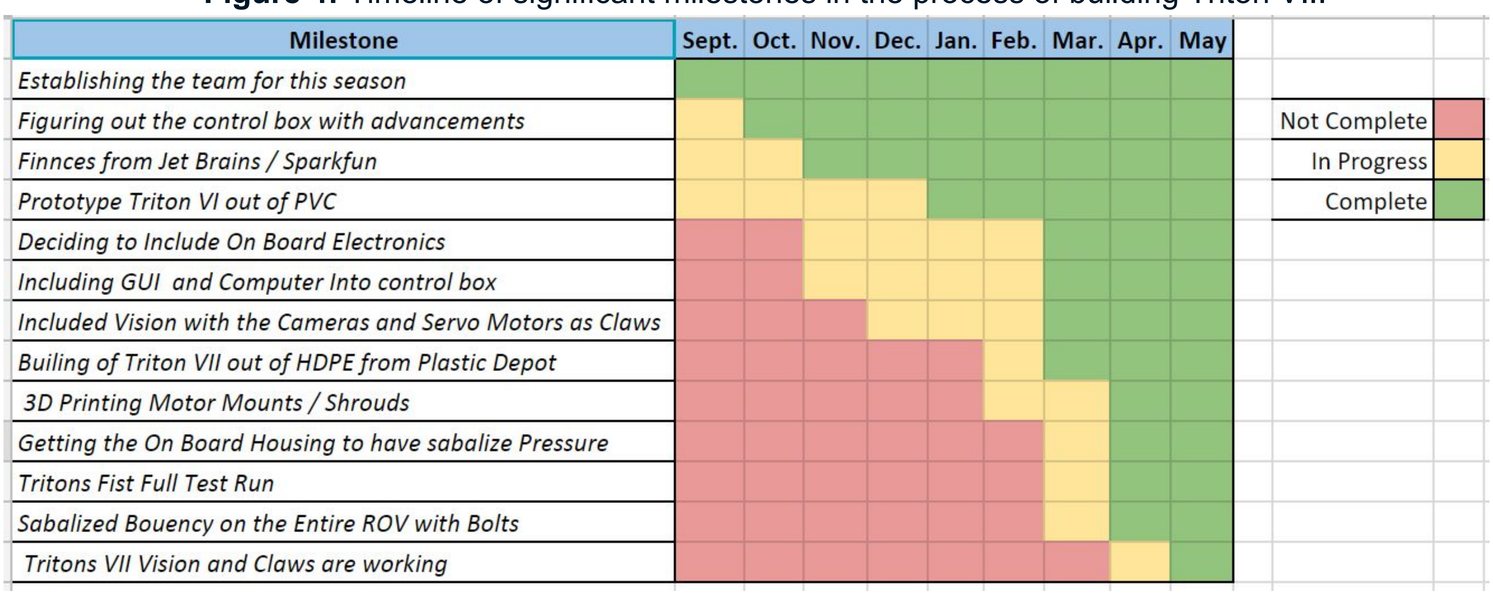
Scheduling and Project Management

45C Robotics began meeting during the summer of August 2017 and met every week for a total of 150 hours. During the school year we met every Sunday for 4 hours. As we approached the competition, extra meetings were scheduled to meet deadlines. In order to ensure our team had plenty of time to complete and practice with our robot, we implemented a strict attendance policy: every team member was required to attend at least 80% of all meetings. Additionally, to ensure every team member fully understood the ROV as it was updated, the CEO hosted info sessions to inform everyone about the latest upgrade of the Triton VII.

Prior to any meeting, each sub-leader would write down what needed to be accomplished on a to-do list to stay on task and complete projects on time. At the beginning of meetings, we would talk about what had been accomplished previously, and what was to be done next. Then, we would split into small groups (2-3 people) based on interest. These groups mingle and switched members throughout the year as every member became involved in multiple aspects of the ROV, helping every member understand every component.

After every meeting, sub-leaders would state what was accomplished, what needed to be done in the next meeting and updated the to-do list accordingly. The to-do list was shared with every member to ensure everyone knows the current pace of progress. As a team, we finished the robot by April to ensure an ample amount of time for pool practice. As we approached even closer to the competition, meetings became more frequent and longer to allow time for troubleshooting, pool practice, technical writing, and presentation practice.

Figure 4: Timeline of significant milestones in the process of building Triton VIII



Safety

A. Safety Philosophy

Safety is our number one priority at 45C Robotics. We identify all possible risks to the robot, team member, or tool, and take the necessary precautions to insure our 100% safety guarantee. We have a strict set of rules to maintain the company's safety for the poolside and development area when working on the robot. Safety masks are used when applying epoxy to components, or when cutting dust-releasing materials. All members are required to wear safety goggles at all times when performing actions potentially harmful to the eyes, such as soldering or cutting. The locations we build in are equipped with mobile Carbon filters, which are utilized to fan out any potentially hazardous fumes. Additionally, all locations are stocked with nitrile gloves for the use of potentially hazardous materials such as epoxy. 45C Robotics constantly maintains the healthy environment of all work places utilized by taking 10 minutes before every meeting to completely clean up the surrounding areas. Cleaning up before construction allows for any clutter to be removed, allowing us to find tools faster, and with less tripping hazards. After every meeting, 30 minutes are taken to clear debris from construction or testing. Doing so ensures a healthy relationship with the locations' maintainers (often parents) to ensure we have a place to work on the ROV. In doing so, we also keep a positive relationship in case sudden meetings are required to use the venue.

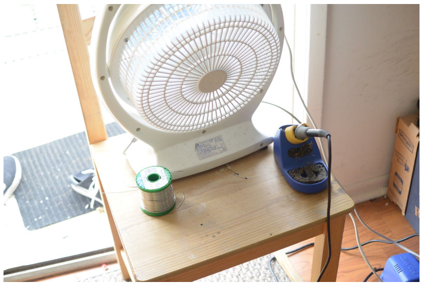
Additionally, 45C enforces various safety measures throughout the manufacturing process of the robot. For example, it is required that all team members adhere to clothing requirements during power tool operation. Clothing requirements include keeping all loose hair tied, no loose clothes, and further machining level standards. Team members are also required to wear safety goggles, and in some cases gloves when using any chemicals potentially harmful to the body. In addition to the MATE Safety Guidelines, 45C Robotics has adopted an additional safety checklist to be observed before and after each water test of the ROV, as shown in section D.

B. Safety Features

Triton VII was developed with an emphasis on safety. "Dry runs" were held periodically to ensure the mechanical and electronic components were working properly before testing the robot underwater. This year, we have integrated the safety checklist into the control box, so that the ROV will not start until all items have been checked (Figure 5B). By doing so, any accidental usage of the ROV underwater while malfunctioning is greatly minimized.

In order to ensure the safety of any organisms near the ROV, we also developed mechanical measures to prevent damage. All sharp edges were deburred, so that no organism can be accidentally stabbed when in proximity of the robot. Additionally, the flotation pads were added at the top corners of the ROV to cover any potentially sharp edges. Doing so ensures that if the robot does collide into an organism, the organism is not harmed. To keep any small components and living things out of the motor blades, shrounds were made to IP-20 standards to keep even a pinky out. More information is provided in the shrouds section.

Figure 5A: *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.

D. Safety Checklist

Figure 5B: *Triton VII's Operating Checklist*

Vehicle Inspection:
- Inspect for sufficient grease on all moving parts and O rings
- Inspect/secure all shafts
- Tighten all propellers
- Ensure the frame is securely attached
- Pressure test housing at 400 mmHg for two minutes

Tether and Tether Management Subsystem:
- Inspect the tether for visible damage
- Ensure the tether cable is neatly coiled
- Ensure proper connection from the ROV to the control box

Electrical Subsystem:
- Ensure all fuses are installed properly
- Ensure plug connectors are secure
- Ensure 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

Ensure PC supply and main supply are properly connected before continuing
Request for start-up clearance

PC PWR........Pressed
MN PWR Switch........ON

If VE PWR switch is dimly lit when ethier joystick are moved upwards, then continue

VE PWR Switch........ON
Cooling Fan Switch........As required
OBS Speaker........Tested
Alarm Test........Press and Hold for 3 seconds
Indicators lights........Checked
Video Signal........Checked
CLAW 01........Checked
CLAW 02........Checked
Vision 01........Checked
Vision 02........Checked
GUI Display........Checked

Shutdown Checklist

Request for ROV shutdown

PC PWR........Pressed
Vision 01........OFF
Vision 02........OFF
CLAW 01........OPEN
CLAW 02........OPEN
OBS Speaker........OFF
Cooling fan switch........OFF
VE PWR switch........OFF
MN PWR switch........OFF

Go to Recovery Checklist

Recovery Checklist

Request for ROV Recovery

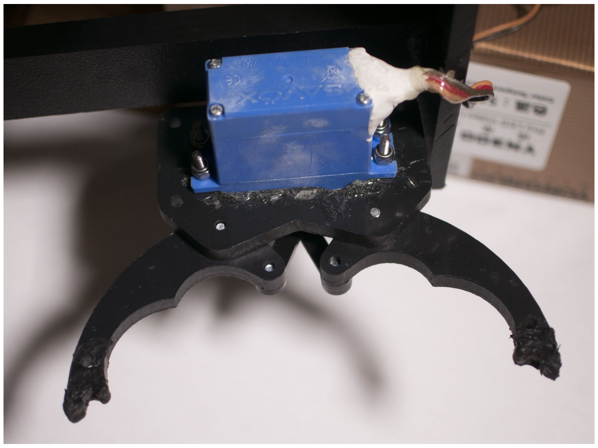
Position ROV close to the deck, then pull the tether slowly recovering the ROV.
Ensure PC supply is neatly coiled and organized in the control box
Ensure Tether is neatly coiled around the ROV vehicle

Design Rationale

A. Mechanical Design

During development, 45C made use of a step-by-step design process to strive for maximum efficiency. Members of 45C Robotics began this process by brainstorming 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, functionality, and simplicity.

Figure 6: *Upper Claw of Triton VII*

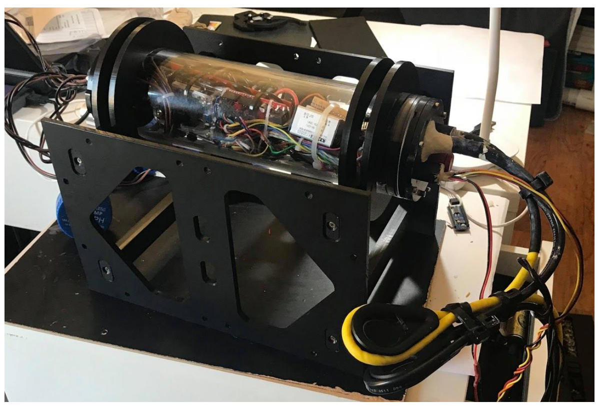


Manipulators

This year, we decided to use a dual claw system for our manipulators. Our system is comprised of a horizontal claw in the front and a vertical claw in the back. By having our manipulators in this format, we have more maneuverability options for prop grabbing. In addition to providing more options, the dual-claw system allows us to hold two things simultaneously, which has proven to be extremely valuable during our testing. For example, we were able to hold one of the props in one claw, while retrieving another prop using the second claw. Last year we used a claw that had an opening width of about 50.8 mm, but this year we are using a claw that has an opening width of 127 mm. The increase in width upgrades the range of motion for the claw and its capabilities.

Frame Structure Design

Figure 7: *Triton VII's Frame Structure*



From our design matrix, we decided to narrow the material choice down to PVC (Poly Vinyl Chloride), HDPE (High Density Polyethylene), and PET-G. Since we used PVC last year, we were already familiar with cutting it. However, using a PVC frame would provide us with limited options for motor mounts and housing mountings. To address this problem we researched two alternatives to PVC that were light in weight, had a sturdier structure, and cheaper in price. From our research, we narrowed down our plastic type to HDPE. We chose to build the majority of our frame using HDPE, because it is impact resistant, lightweight, water resistant, and long lasting. More factors included in our decision to use HDPE rather than PVC can be found in the decision matrix.

	Cost	Rigidness	Cutting	Desity	Mosture Absobsation	Astetics	Total
HDPE	-1	1	1	1	1	1	5
PVC	1	1	1	-1	1	-1	4
PET-G	-1	1	0	-1	1	1	3
Acrylic	-1	1	0	-1	1	1	3

Figure 8: *Decision Matrix of Material Choices*

Figure 9: *3D Printed Mounts*

Motor Shrouds

The Triton VII motor shrouds were 3D modeled in FreeCAD and 3D printed on a Makerbot Replicator Mini using PLA plastic. In analyzing our shrouds from our Triton VI last season, durability, material usage, vibration diffusion, and visual appeal were deemed the most important factors for the design.

The Triton VII frame was designed with identical mounting pockets for all the support brackets and motor mounts, (25.4 mm by 12.7 mm, 4.76 mm radius) to reduce the number of CNC operations on the ROV frame, resulting in a cheaper manufacturing cost. Because of this design, the motor shrouds were designed to fit according to the uniform mounting pockets. We concluded that the large surface area and tight mate between the A shroud and the ROV frame would diffuse more vibration, compared to the smaller 12.7 mm circular PVC mount that we had last year.

Both the A shroud and the B shroud are tapered compared to our last year's design, to use less material. Following this concept, we printed our shrouds in two pieces, as to save even more material. Our shrouds last year were also printed in ABS and fractured easily during transit, so this year we decided to print them in PLA.

Lift Bag

This year, MATE integrated lift bags into the manual. Lift bags are devices that are attached to objects underwater, that lift the object to the surface once activated. A lift bag is required in Task 1, where the ROV has to inflate the lift bag and recover part of the airplane wreckage. At first we were going to construct our own lift bag, using some sort of rubber waterproof material. However, after conducting some research, we found that constructing a lift bag would be expensive, and even after buying the materials, there would be no guarantee that it would work. Because we had limited time, we decided to buy a lift bag, as we had the budget, but didn't have the time. We incorporated the hose of a manual air pump (Figure 11), donated to us by Etisone, into our tether. The hose ran all the way from the surface to the front of the ROV where it was positioned pointing up so that the camera could see it and so that it could be easily positioned under the lift bag to inflate it.(Figure 10).

Figure 10. *Lift Bag with hose*

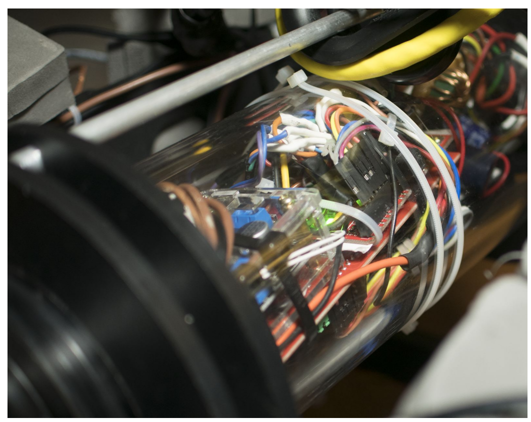
Figure 11. *Air pump with hose*

B. Electronics Design

Onboard Electronics Enclosure

The onboard electronics consist of two Arduinos, one relay board (with eight relays), and three voltage regulators. These components were placed in a 76.2 mm diameter acrylic tube with a length of approximately 300 mm. The on-board housing allows us to use a thinner tether, and increases speed for the motors due to the housing’s lower voltage drops. This year, a 5 volt switch mode power supply was also added to power our relays and Arduinos. In order to increase the torque and speed of the servo motors, we used another switch mode power supply at 6 volts, connected to the two servos on the manipulators (claws).

Figure 12: *On Board Electronics*



One Arduino converts analog signals from the joysticks to the relay motor controllers. The second Arduino is used to convert the digital button input into pulse width modulation signals for the servos. We chose to use relay motor controllers as they were much cheaper than ESC controllers, and did not not experience any voltage drops during our testing. We also chose them because they were capable of handling high EMF forces from our inductive load motors.

The four motors had a total of eight high gauge wires, making it impossible to fit all eight wires under one parameter connector on the onboard housing cap. To solve this, we decided to replace the dome end cap with an additional aluminum end cap, so both sides of the acrylic tube could be allocated to hold the high gauge wires. The front end cap was allocated for the servos, main power, communication tether, and vent hole. The back end cap was allocated for the four cable connectors for each motor. This design allowed us to keep the frame small, as it reduced the need for a larger acrylic housing.

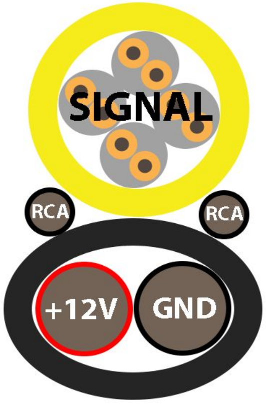
Figure 13: *Backup Camera*

Cameras

Triton VII utilizes two analog car backup cameras with a waterproof rating of IP69K. These cameras are connected via RCA cables and run down the entirety of the tether. To ensure that the camera's flickering was reduced to the minimum, we designed a custom made LC Pi Filter utilizing an empty PCB board. We originally used a regular LC low pass filter, but the filtering was not effective enough. We decided to upgrade to two capacitors for filtering, rather than just one, for the input. The cameras were placed in an appropriate position that provided a wide view of our tools as well as the props underwater. These analog camera signals are converted into digital signals with the assistance of two USB video capture cards. The digital signals then go to our computing systems, where they are used for camera vision and multiplexer.

Tether

Figure 14: *Tether Design*



The Triton VII's tether consists of two 10 AWG wires for 12 volt and ground, eight 26 AWG wires for communication, and two RCA cables for the cameras. Our communication wires consist of both digital and analog signals, depending on the information sent from the control box. The buttons within the control box send a signal of either positive 5V or zero, with the amperage limited by a resistor to prevent shorting. The potentiometer joysticks send an analog signal of varying voltages between zero volts and positive 5V. We originally tried to send digital communication signals using two Arduinos, but they were unable to communicate with the ROV due to wire resistance caused by the length of the tether.

Figure 15: *Bilge Motor*

Motors

Triton VII has four 1100 GPH bilge pump motors: two for vertical motion, and the other two for horizontal motion and yaw motion. These motors were chosen because they had the best price to gallons per hour ratio. This was a huge improvement from the motors that were used last year, as those only had a GPH of 500. All connections for the motors go in directly to the electronics housing, as this prevents the need for waterproofing solder joints. The leads for the motors go in the electronic housing back end cap as mentioned in the Electronics Enclosure section. This design allowed for a much easier wire organization system.

Control Box

Figure 16: *Control Box Systems*

This year we designed our control box from an aluminum briefcase. The top of the briefcase consists of a 16:9 1080p display from a cheap monitor. We removed the monitor's casing, along with its electronics, and attached the LCD display to the lid. The display controller was glued to the bottom side of the case. Heatshrink was added to protect the wires from tearing, and MDF board was used for the buttons as well as the monitor housing. An 200 mm touchscreen display was added to the bottom side of the control box for pilot assistance. The display is connected to a Raspberry Pi 3 with an Arduino for serial monitor. The main display is connected to a desktop PC with Nvidia Geforce graphics card and an Intel Mobile i7 processor. The main desktop PC consists of our Python multiplexer and camera vision. We chose to program our own video multiplexer from Python and Java because commercial ones were too expensive and not reliable. We originally wanted to use a Raspberry Pi 3 for the software but it was not powerful enough to run our vision and multiplexer.

C. Software Design

Version Control

Any team member programming the ROV is required to save any progress by committing to the project on GitHub. By doing so, a backup of the program is available in case our robot code malfunctions. Additionally, team members are encouraged to comment on any code they write, so others can easily understand iterations of the code.

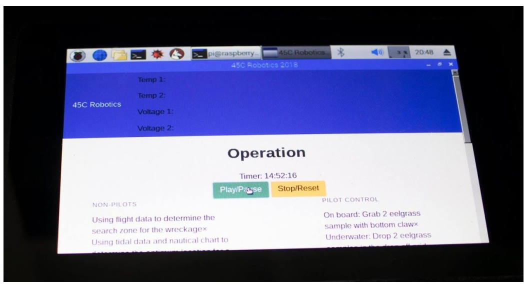
Test-Driven Development

We also incorporate Test-Driven Development (TDD), by testing each individual function logically before porting the code to the main robot. This way, we can avoid any problems or fatal software issues that could have occurred, had we uploaded it directly to the robot.

OBS

To control our OBS speaker, we integrated the MAX9814 Microphone Amplifier Board Module with an Arduino Nano board. We used the capabilities of the module to reason that voltage could be calculated using the graph of the microphone. In testing the voltage received by the module underwater when the OBS speaker is on, we created a range of acceptable voltage levels in which the robot should open its front claw.

Figure 17: *Touchscreen Display*



Graphical User Interface

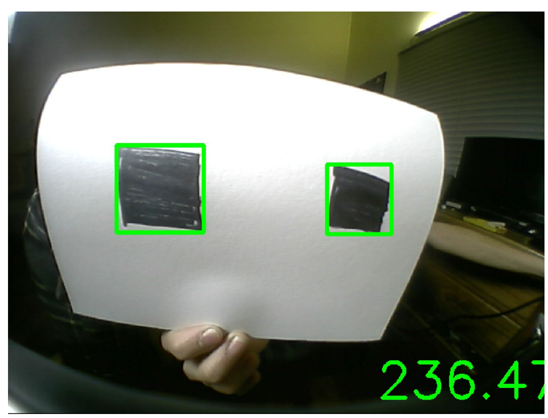
This year, we aimed to improve the design and functionality of our ROV's engineering, particularly with its software design and development. To incorporate the mission timer, safety procedures, and driver operation tasks, we installed a Raspberry Pi 3 to the control box to run its operation Graphical User Interface (GUI).

To build the interface, we chose to experiment with web development technology (HTML5, CSS, and Python) in order to quickly prototype a desktop application. To accomplish this, we used the htmlPy Python module, which allowed us to incorporate CSS modules to build an elegant GUI design within Python.

The GUI interfaces with another Python file ran on the Raspberry Pi which continually updates the interface with system state (voltage and temperature) information.

Camera Vision and Display

Figure 18: *Vision Demonstration*



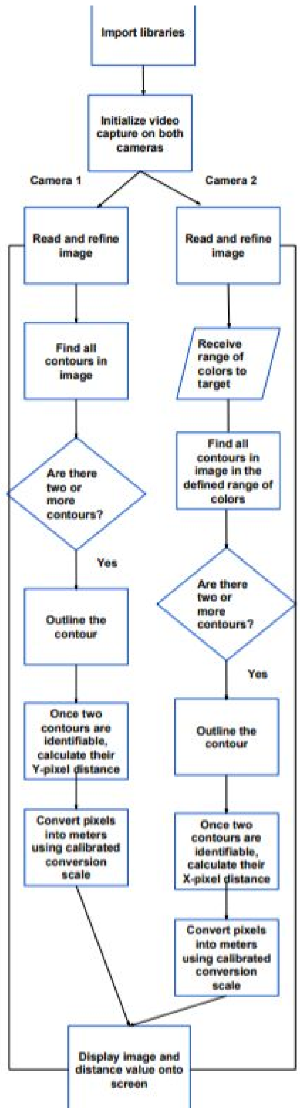
This year, instead of manually measuring distance-related information, we decided that computational power would give us consistent, accurate, and rapid results. Triton VII's camera outputs are processed using the OpenCV Python library, in which both cameras on the robot are able to identify and process visual input.

To write the software for computer vision, we first had to look at our goals mathematically. We discovered that OpenCV is able to determine moment of inertia values of *contours* (a conjoined, continuous set of points, which is the basis of our vision programming), which allowed us to calculate the distances of two contours' center of mass.

However, OpenCV is only able to calculate physical units in terms of pixels, as different cameras have different internal specifications. Thus, we calibrated our cameras by calculating the ratio of pixel distance to real distance (in meters).

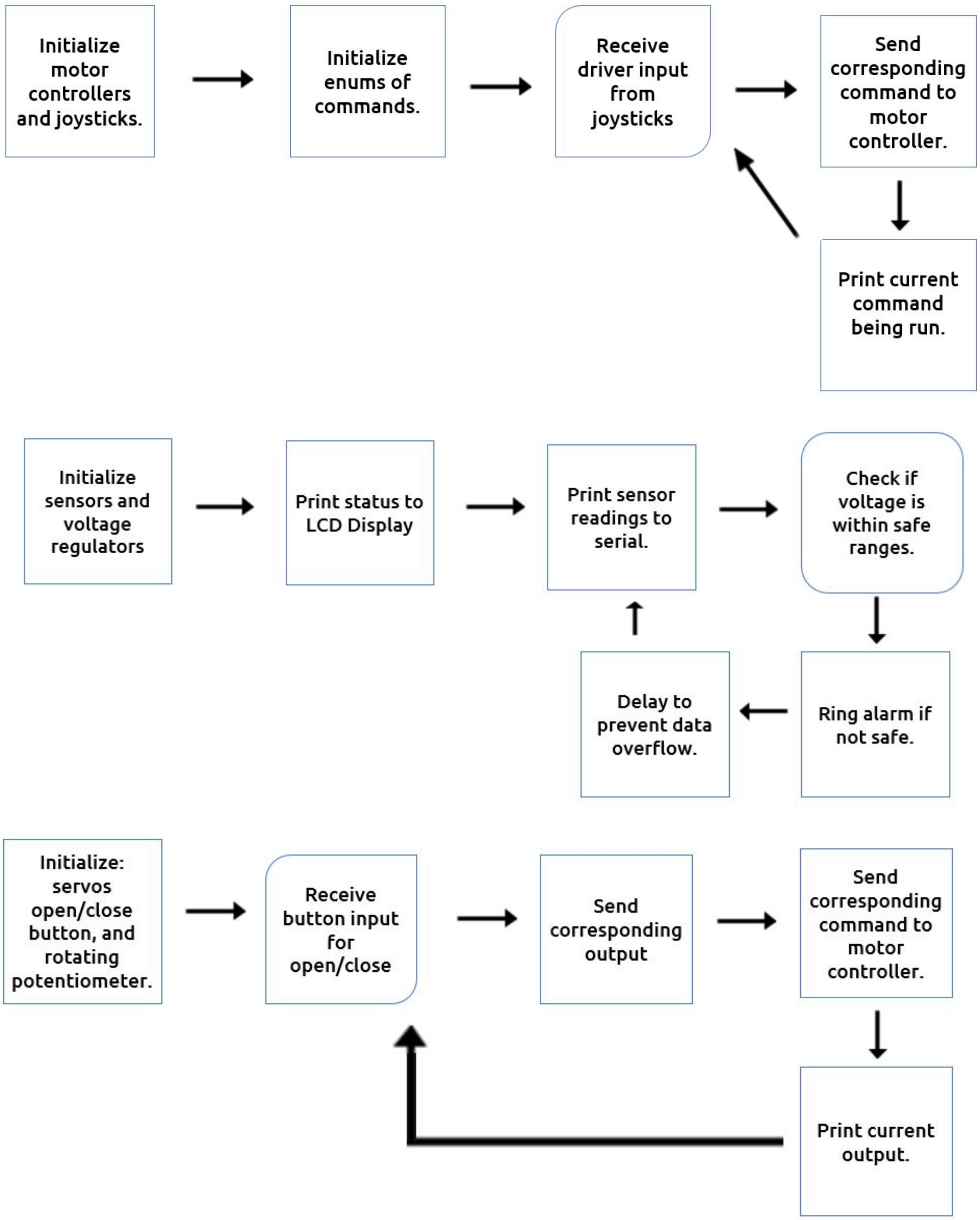
We also set out to use other capabilities and modules of the Python programming language to produce an optimal and efficient experience for the pilot. In the case of a software failure in which we are forced to use physical equipment for distance tasks, the pilot is able to toggle the state of vision on either camera by pressing a button on the keyboard.

Figure 19: *Vision Code*



Arduino Software

Figure 20: Arduino Codes



Testing

To ensure that every element of the Triton VII functioned to the best of its ability, we conducted several tests on the robot. The individual components on the robot were tested, as well as the robot as a whole.

Housing

We tested our watertight housing using a vacuum pump and concluded that the enclosure was able to sustain 635 mmHg (approximately 12.28 psi) for at least 15 minutes. This test was performed to ensure that all seals on the housing were watertight. The aforementioned vacuum test was performed anytime the watertight enclosure was opened or closed, and before any test dive in the water.

Control Box

We used the combination of an oscilloscope and multimeter to insure all of our critical electrical components were safe. This prevented our circuit boards from damage due to possible high EMF forces from inductive loads.

Claw

The claw was tested by using a scale to determine the torque and grip of the claw. From this, we were also able to determine the strength of the claw to be 3kg. This is well then enough to pick up all the tasks for the competition.

Motors

Using a spring scale, we created a motor testing rig and tested the thrust of our four 1100 GPH thrusters. We did this in order to ensure the actual thrust of our motors, and whether it had enough thrust to maneuver the robot. The thrust of each motor is 1.875kgf when going forward.

Finances

Budget

Since 45C Robotics was in its first year of independent operation (as a club rather than an elective course), we had to pitch to CAMS in order to gain funding. After successfully communicating the importance of the MATE ROV Competition to the school, 45C Robotics received $1000. Additionally, our mentor suggested we should try pitching to Davis Reed Constructions Inc., a construction company. After contacting Davis Reed Construction and pitching to them, we gained an additional $2,000 sponsorship. The donations were processed through the school banker, but the banker quit and the money was frozen, so we scrambled for methods to gain immediate cash to develop the robot as soon as possible.

First, we sought after running a sponsorship campaign. The program consisted of sending a document of sponsorship packages, along with personalized messages to companies relevant to components used on the ROV. In the beginning, the campaign was not producing any results, so we turned to other options. We sold customized keychains and asked for donations at every outreach event we attended, which raised $172. Then, we used the $100 amazon gift card from the 2017 MATE ROV Safety Award. By March, the companies we had contacted began responding, and we was able to gain a 10% discount from Blue Robotics, which surmounted to $100 in savings after purchasing items. Additionally, we gained a $500 sponsorship from Sparkfun Electronics Inc. for electronic components, along with a free account for PyCharm - an Integrated Development Environment (IDE) - which was used to program the robot. Any other costs were covered individually by we members, and will be reimbursed after the school's banker situation is figured out. Any leftover money is to be utilized for future transportation costs for the regional or international competition. In addition, the team held a gofundme campaign to raise $370 and sold rulers from Yun PCB Inc. (a fellow sponsor), raising $200. Our mentor negotiated with our school and travel agents to lower the cost of transportation as well. Thanks to these efforts, the total costs for renting hotels and buying plane tickets was reduced to $440 per person, which resulted in a total cost of $3080. This cost was covered individually by each team member.

Build vs Buy

At 45C Robotics, most of our mechanical and electrical systems are self-built, but we decide to buy our components for our major systems (specifically our propulsion and optical systems) under certain circumstances. We ask two questions to answer the question of "Build or Buy?": can we reasonably build an alternative to the system, and if so, would it cost more time and money to build such an alternative? If the answer is no, or it'd be cheaper to buy, we'd buy the component.

The main components we bought were the Blue Robotics tether, onboard electronics mount, and lift bags. Last year we crafted the tether ourselves, thinking the task would be quite simple. However, we faced many difficulties, such as the buoyant attachments for the tether moving, leading to hours wasted on perfecting the buoyancy for the tether. From our difficult experience from last year to find neutral buoyancy for the tether, we decided we would buy it this year to save time. Other than buoyancy, one major problem we faced last year was waterproofing. We often take hours applying waterproofing materials to each component to insure water-damage is prevented. Since the onboard electronics are complex and critical to the ROV, we deemed it'd take too much time, and risk to waterproof the onboard electronics. Therefore, we decided to buy the Blue Robotics Onboard Electronic housing, since the housing is extremely reliable in terms of waterproofing, and is easily attachable to the ROV. Initially we attempted to build lift bags using plastic bags. However, after hours of testing different methods, we still couldn't find a way to create an efficient lift bag. We were severely behind on the development of the robot due to the time we put into the lift bag. Therefore we deemed it best to buy the lift bag to save time.

New vs. Reused

Since we were initially low on funding this year, we esteemed cost efficiency as paramount during our design process. In order to save money, we re-used as many components from our last ROV as possible. However, since components such as the camera and servos frequently had waterproofing problems, they had to be replaced often.

Project Budget

At the beginning of the season, our finance lead laid out a budget plan to estimate expenses, based on last year. With a target in mind, the finance lead led we in raising funds in various methods as aforementioned. Before making any purchases, we held a voting poll on messenger to ensure everyone agrees that the component being bought is worth the cost. Whenever a purchase was made, the receipts were collected and saved for future reimbursement by CAMS. Each receipt was then recorded into the Budget sheet attached below. Additionally, any funding gained was added into the Budget sheet to keep track of excess funding which can be utilized for future ROV projects or transportation costs.

Reflections

Challenges/Lessons Learned

Many technical challenges were faced this year while developing the Triton VII. The first challenge we faced was with constructing the onboard electronics. We originally allocated the 4 holes on the on-board housing for wires going in and out of the ROV, but those connections proved to have waterproofing issues, and not all of our wires fit through the holes. This resulted in us using the 4 extra connectors on the back of the housing, but even with that, the tube still could not hold a pressure of 400 mmHg. Eventually, with enough material experimentation, the housing passed our vacuum test after using Epoxy Putty to coat the main power wires.

Aside from waterproofing, we also had issues with the electronics. We were unable to move the servo when PWM signals came from the communication tether. This prompted us to add another Arduino onboard, as the PWM signals experienced high voltage drops along the length of the tether. Because we did not have much space to spare, we ended up using an Arduino Nano to accomplish this task.

On the control box, we had major problems when using the Raspberry Pi to run our vision software. We originally tried to overclock the Raspberry Pi by using a custom-made aluminum heatsink, but even that was not enough to efficiently run our vision software. This prompted us to add a full-size desktop PC to the control box.

Fortunately, the PC was able to fit into the control box, but we were faced with another problem. The desktop's processor had to reduce speed significantly due to overheating (caused by the lack of ventilation in the control box). To draw heat away from the processor, we added a powerful 12 volt DC fan near the heat pipes of the desktop PC.

We also ran into errors when running multiple USB Cameras for our vision display system, which we eventually deduced was a problem on the USB Controller. We fixed these errors by lowering the cameras' output resolution and frame rate.

A thermocouple was also added to the heat pipes in order for our GUI system to display the temperature. The desktop no longer thermal throttles after the inclusion of a separate fan. The surface of the control box was also a lot cooler at 30 degrees Celsius as supposed to 37 degrees.

Future Improvements

There are a few key things that we would like to improve for next season of ROV. During the beginning of this season, we originally wanted to just use a simple PVC frame. It was not until near March that we decided designing a custom frame would fit our electronics and manipulators better. We should have also planned our tether and onboard electronics design sooner. The decision to use onboard electronics was not fully settled until the end of February. This gave us very little time to finish the electronics design and frame assembly. If we had more time in these areas, it could give us more practice time. For next season, we should plan these major design choices near the beginning of the season so we would have more time to plan out different designs and have more time for testing and practicing. We should also more frequently use the list of things we need to accomplish each meeting to increase productivity. Lastly, we should set due dates for each individual parts so they can eventually all come together.

Team Reflections

"During this past year with 45C Robotics, I've learned the most important part of teamwork. A team is not just about winning the competition but also we itself. This year was also the first year when we started using advance software and electronics. We kept pushing beyond the limits of what we thought was possible. We are not stopped by challenges that we face but instead we embrace those challenges and make them work."

Jiajer Ho, CEO, Electrical Lead, and Designer

“This year has been the biggest push we’ve strived for, not just in terms of software but in terms of all our components as well. Throughout the season, we’ve used technologies and software practices that were at first foreign to us, but we kept experimenting and kept innovating, which I think 45C Robotics is all about. ”
Isaac Addis, Programming Lead

“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 Lead

“This year in 45C Robotics we definitely had many struggles, as well as a huge amount of improvement from last year. We passed these difficulties through laughter, patience, and hardwork. As this is my third year on this team, I have watched us grow together, and I believe teamwork is the most important when faced with challenges. ”
Celia Yu, Mechanical Co-Lead

“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 second year, I learned a lot and I’m glad our team has been performing wonderfully.”
Kentaro Vadney, Finances Lead and Machining

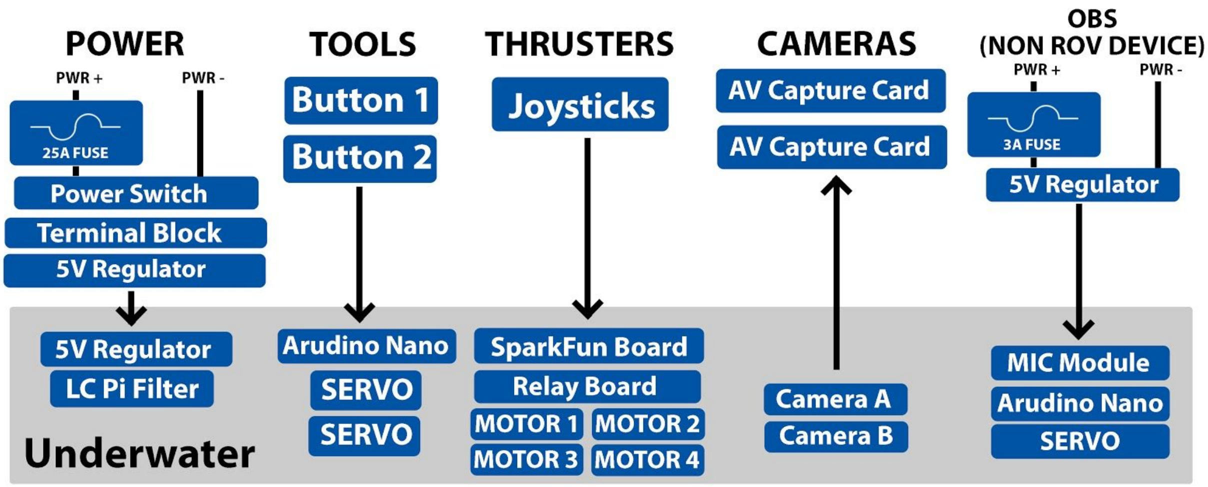
“I have worked with many robotics teams at California Academy of Mathematics and Science but I have never worked with a more passionate team as 45C Robotics. Being new to the team, it was a great experience to not only watch *Triton VII* grow, but also our skills and experiences with each other at every meeting. Since I am heading for the real world, I am thankful to be part of such a motivating, inspiring and loving team.”
Etisone Escamilla, Mechanical Engineer

Appendix

A. Electrical Diagram

Figure 21 and 22: Fuse Calculations and SIDs

Fuse Calculations			
Component	**Current Draw**	**Quanity**	**Total**
Thrusters	3.2	4	12.8
Servo	1.3	2	2.6
Camera	0.12	2	0.24
Monitor	0.3	1	0.3
Relays	0.02	8	0.16
LED Lights	0.02	1	0.02
Arduinos	0.01	2	0.02
Total Current	**16.14**		
Current * 150%	**24.21**		
Fuse Needed	**25**		



B. Budget Sheet

Figure 23: Budget sheet

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
Arduino Uno and Arduino Nano	N/A	Used for control system	$ 21.43
Buttons	N/A	Used for control system	$ 15.42
Voltage Regulator 5 Volt 10 Amps	N/A	Used for control system	$ 2.14
Voltage Regulator 5 Volt 5 Amps	N/A	Used for control system	$ 1.32
Voltage Regulator Adjustable	N/A	Used for control system	$ 3.51
Clamp and Screws	N/A	Used for Frame	$ 4.22
Waterproof Housing Kit	N/A	Used for Frame	$ 30.50
Blue Robotics Tether	N/A	Used to connect ROV to Control box	$ 75.00
10AWG Power Wires	N/A	Used for control system	$ 33.50
HDPE Frame	N/A	Used for Frame	$ 60.00
Blue Robotics Onboard Electronic Mount	N/A	Used for Onboard House	$ 114.00
Buoayancy Foam	N/A	Used for Buoyancy	$ 10.25
Bolts	N/A	Used as ballast	$ 12.00
3D printing filament	N/A	3D printed Shrouds / Motor Mounts	$ 17.00
Lift Bag	N/A	Used for lifting	$ 100.00
		Total	**$ 498.56**

Total Reused Items			
Description	Donor	Notes	Value
Lucas Oil Marine Grease	Old team	Used for Moving Parts	$ 6.49
IP 69K Cameras	Old team	Used for control system	$ 32.00
Strain Relief Connectors	Old team	Used for Tether	$ 9.74
ABS/PVC Glue	Old team	Used for vehicle frame	$ 8.51
Fuse Holder Connector	Old team	Used for control system	$ 12.41
Adafruit Analog Mini Joystick	Old team	Used for control system	$ 62.15
Johnson Pump Motor	Old team	Used for control system	$ 103.04
Motor Propellers	Old team	Used for control system	$ 15.63
Video Camera Wire	Old team	Used for control system	$ 10.40
Savox Servos	Old tean	Used for OBS	$ 36.99
		Total	**$ 260.37**

International Transportation Costs			
Description	Donor	Notes	Amount
Hotel and Airflight costs	N/A	$440 per 7 people	$3,080.00

Money Donations		
Description	Sources/Notes	Amount
Blue Robotics Discount	N/A	$ 100.00
Team Donations	N/A	$ 256.00
Outreach Donations	N/A	$ 172.00
2017 Safety Award Amazon Card	N/A	$ 100.00
School Donation	N/A	$ 1,000.00
davis REED Construction Inc.	N/A	$ 1,000.00
Gofundme	N/A	$ 370.00
Selling Rulers from Yun PCB Inc.	N/A	$ 200.00
	Total	**$ 3,198.00**

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 Donated Items			
Description	Donor	Notes	Value
Lead free solder	Yun Industries	Used for Wires	$ 8.64
Zip Ties	Yun Industries	Used for Tether	$ 10.42
Raspiberry Pi 2	Sparkfun Inc.	Used for Tether	$ 30.95
Raspiberry Pi 3	Sparkfun Inc.	Used for Tether	$ 39.95
Arduinos	Sparkfun Inc.	Used for Thrusters	$ 59.85
Buttons and Switches	Sparkfun Inc.	Used for control system	$ 10.50
Waterproof Servos	Sparkfun Inc.	Used for control system	$ 85.90
Touchscreen DIsplay	Sparkfun Inc.	Used for control system	$ 64.95
Claw Systems	Sparkfun Inc.	Used for Claw Gripper	$ 18.95
Tempeature Sensor	Sparkfun Inc.	Used for control system	$ 9.95
Resistors	Sparkfun Inc.	Used for Electrical System	$ 7.95
Monitor	Team Parent	Used for Thrusters	$ 70.81
Metal Case	Team Parent	Used for Claw Gripper	$ 5.00
Computer	Team Parent	Used for control system	$ 500.00
15 meter air hose	Team member	Used for lift bag	$ 20.00
Manual air pump	Team member	Used for lift bad	$ 5.00
		Total	$ 923.82

Total ROV Cost	**$ 1,682.75**
Total Donated/Reused	**$ 4,382.19**
Total left over	**$ 2,699.44**

Acknowledgments

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- Yun Industrial Co Ltd for material and equipment donation
- JetBrains for software donation
- Davis Reed Construction Inc. for cash donation
- Garnet Pool for ROV testing purposes
- California Academy of Mathematics and Science for supplies donation
- Sandra James for material donations and aid in organization
- Joseph Carpenter for 3D printing technical expertise
- All the volunteers and staff at the Long Beach Regional event

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