Crusader Robotics

Brother Rice High School, Chicago, IL

"Crusader Robotics… A Crusade for a Better Tomorrow"

Name	Robotics Title	Future Career Goal
Jack Clisham	Mechanical Engr.	Computer Science
Liam Coughlin	VP Electrical Engr.	Engr.
Andrew Cwik	Idea Generator	Engr.
Peter Cwik	Recruitment	Computer Science
Tyler Davros	Idea Generator	Fireman
CJ Dvorak	Prop Master	Computer Hardware Engr.
Ryan Kaczynski	Sysadmin/Network Engr.	Computer Hardware Engr.
Malcolm Kindle	Idea Generator	Electrical Engr.
Sean Kenny	Sysadmin/Network Engr.	Mechanical Engr.
Jack McBrearty	VP of Mechanical Engr.	Biomedical Engr.
Matt McCormick	VP of Technical Writing	Biomedical Engr.
James McManus	VP of R&D	Automotive Designer
Frankie Mesec	Idea Generator	Biologist
Pat Nielsen	Company CEO	Electro Mechanical Engr.
Tim Novick	Idea Generator	Engr.
Nico Perez	Idea Generator	Engr.
Ryan Rice	Mechanical Engr.	Computer Science
Joe Taylor	VP Mechanical Engr.	Mechanical Engr.
Pat Walsh	Marketing	Systems Engr.
Vince Zampillo	VP of R&D	Engr.

Mentors: Dan Mostyn and Eric Gamboa

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MATE 2017 Technical Document

Abstract

MATE 2017 Technical Document

Crusader Robotics has been operating in Chicago, IL since 2014. The design process of the ROV (Remotely Operated Vehicle) initiated with team members sketching concepts and constructing prototypes using Knex. Two models of PVC were created and the most effective was modified into one design. The first task, "Commerce: Hyperloop Reconstruction," involves the ROV assisting in the construction of hyperloop tunnels offshore to make port operations more efficient, inexpensive, and eco-friendly. The ROVs claw installs rebar reinforcement rods, removes a pin, and transports a hose. Attached velcro helps retrieve construction positioning beacons. The second task, "Entertainment: Light and Water Show Maintenance," involves repairing a popular attraction. The ROVs claw and custom valve turning motor helps to turn a fountain off, perform maintenance, and turn it back on. The third task, "Health: Environmental Cleanup," concerns an environmental remediation project to remove contaminated sediments at the Long Beach port. The ROV uses a flashlight to simulate a Raman laser to view possible contaminants in a clam bed and the agar collector retrieves a sample and returns to the surface. The claw and clam basket retrieve two clams and place the cap over contaminated sediments. The fourth task, "Safety: Risk Mitigation," uses the cameras to locate abandoned cargo containers. The claw holds an RFID sensor to identify the containers and their contents. A modified mouse trap attaches a buoy to the container with the highest-risk cargo. Crusader Robotics designed the ROV to perform for a real port city anywhere in the world.

Completed ROV Pictures

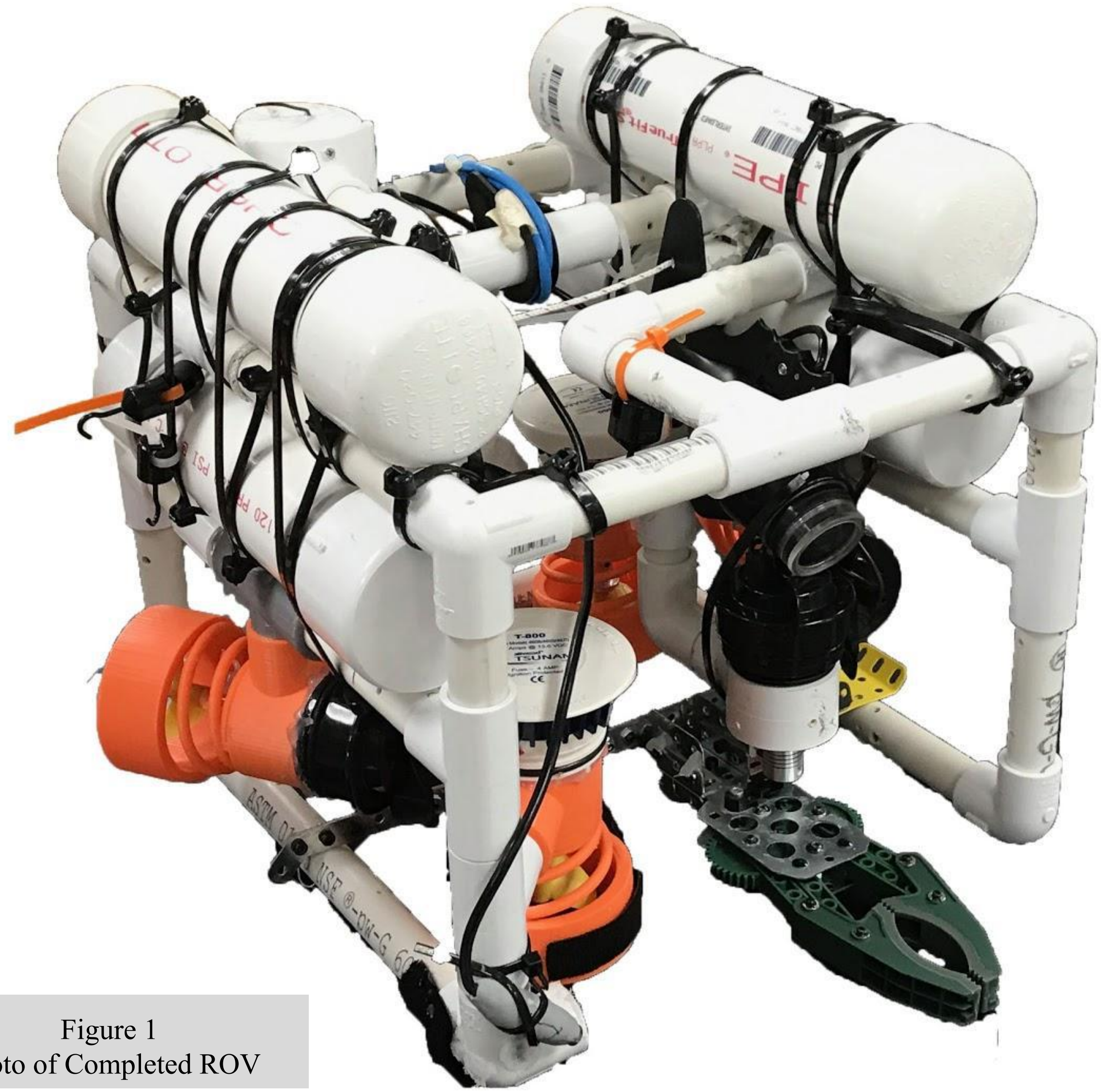


Figure 1
Photo of Completed ROV

- **Weight on Land = 6.21kg**
- **Weight in Water = 1.8kg**
- **Size = 36cm x 35cm x 30cm**

Design Process

The company started the design process by sketching multiple early-stage designs on sheets of paper. After discussion of each design, the team narrowed down to a small group of prototypes that were made out of K'NEX (Figure 2). After these were developed, they were further analyzed by the team, and two final designs were chosen to be constructed into prototypes out of PVC. Several team members split into two groups, each focusing on the design of one prototype. After both prototypes were finally completed, they were rigged with electronics and motors and tested in the pool. After evaluating the pool runs and going over pros and cons of each design, a democratic vote was held to determine which design would be chosen. Because Crusader Robotics values everybody on the team being involved, a democratic voting process was often used to make important decisions. A majority of the company also voted on the claw we use (Figure 5).

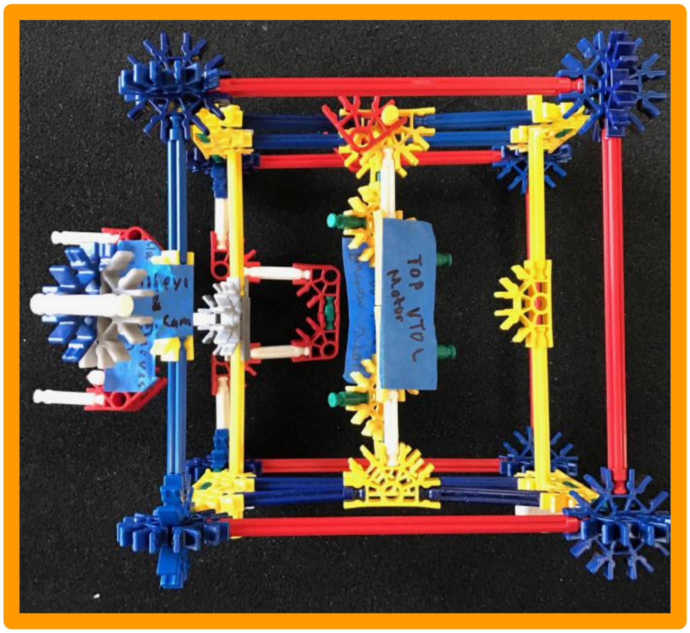


Figure 2
K'NEX prototype

Design

Frame: The company decided to build a rectangular frame. The frame is constructed out of PVC pipe because it is inexpensive and durable. The PVC is also very light and keeps the ROV under the weight constrictions (Figure 3).

Figure 3
Early Frame Prototype

Motor Layout: The motors' positioning was designed to maximize movement. Edmund Mk. III has five main motors for movement. The two side motors are slightly tilted left and right to decrease the time it takes to turn the ROV. Two downward facing motors are designed for vertical movement. The bottom-front corner and bottom-rear motors are diagonally across from each other to keep the ROV level when maneuvering vertically. The center-rear motor is used for horizontal movement. Motor placement is very important in the real world because the ROV needs to perform its best of its ability in the water. If the placement is unbalanced, than the ROV could have trouble moving.

Figure 4
Back of ROV

Tools

Claw: The company chose this claw because it has a strong grip, is very reliable, and operates with a waterproof bilge pump cartridge. The claw is the most versatile tool on the ROV, performing a number of tasks. The claw has been placed on the ROV specifically to do the following product demonstration challenges: grab the rebar rods, the pin, concrete hose, power cable, locking mechanism, fountains, clams, clam bed cap, measuring rod, and RFID sensor. In real life, the claw could be used in construction, maintenance, environmental cleanup, and work with unsafe materials (Figure 5).

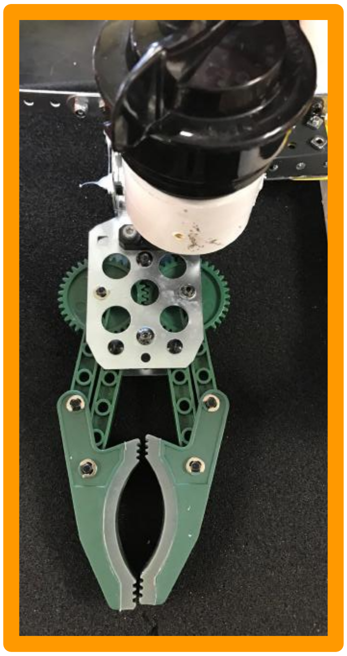


Figure 5
Claw

Raman Laser Simulator (Flashlight) & Agar Collector: The Raman Laser Simulator and Agar Collector are designed as one unit to make the ROV more compact and efficient. Thus, when the ROV hovers over the agar container, the flashlight can be turned on to identify the substance and then collected by the agar collector immediately afterwards. The agar connector splits into two so the team can collect the agar when it has been returned to the surface. This achieves the task of studying for contaminants in certain areas that could be polluted. (Figure 6).

Figure 6
Agar Collector/Flashlight

Tools

Valve Turner: The valve turner was designed to open and close the water valve for the water light show maintenance task. It is driven by a stepper motor that is controlled by two buttons. The motor is encased with toilet bowl wax, vaseline, and a custom 3D printed shell to keep it waterproof. A spring connector joins the motor and 3D printed prongs together. The prongs are designed to fit smoothly on the PVC and maximize torque. This could be used by entertainment groups to perform maintenance on fountains and shut off water flow to those fountains (Figure 7).

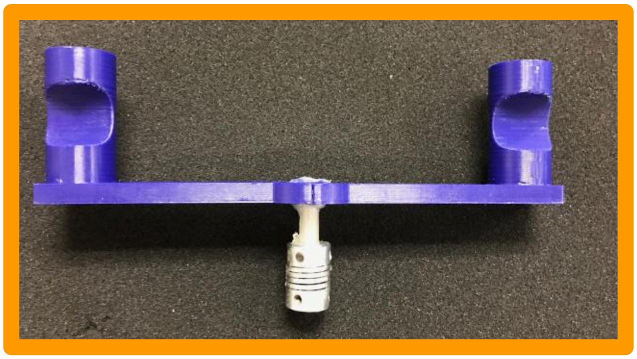


Figure 7
Valve Turner Attachment

Figure 8
Measuring Stick

Measuring Stick (The Hot Dog): The measuring stick is used in making the survey map for the cargo containers. The claw drops it down beside the containers, and a crew member then takes a photo with all the containers and the stick. The stick (25cm) is a known length utilized to determine the length of the containers. A rope is attached so tether crew can remove it from the water (Figure 8).

Tools

Figure 9
Mouse Trap
Buoy

Mouse trap buoy: The mouse trap buoy is used to mark the most dangerous cargo container. The mouse trap and buoy are connected with a long rope. When triggered, the mousetrap locks onto the U bolt securely. Liquid electrical tape is placed on sharp edges for safety (Figure 9).

Figure 10
Velcro on the front of ROV

Velcro: The velcro helps in retrieving the three positioning beacons. The velcro is positioned in the front of the ROV so that the team can use the main camera and easily see the beacons. These beacons are used in underwater construction for hyperloops (Figure 10).

Connections

3D Printed Connector: Our company 3D printed a custom PVC connection in order to keep the ROV compact. The 3D connector also offered new angles and placements for motors and other tools. (Figure 11).

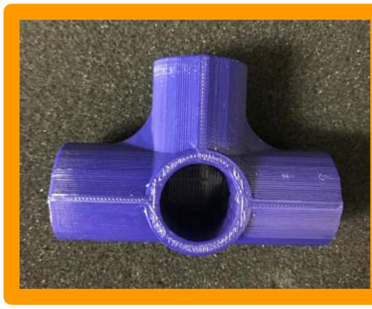


Figure 11
3D printed PVC connection

Camera System

Waterproof Fish Camera: The fish camera is the ROV's main camera. It provides a clear view of the front of the ROV and its surroundings. Our company chose to buy this for the main camera because this model has a history of reliability. It has already been professionally waterproofed and is designed to be in the water. It sits in the center of the ROV (Figure 12).

Figure 12
Fish Camera

Figure 13
USB Camera

USB Plumber Camera: The ROV has two USB cameras to provide additional views. One camera is positioned downwards to see the cup of agar. The other camera is positioned in the front to help assist the claw in positioning the rebar rods into the baseplate. The cameras work using two raspberry pis that are in the control box on land. The cameras are already waterproofed but our company placed puddy as an extra precaution. (Figure 13).

Control System

Main Control Box: One improvement we looked to make was to improve our organization. The main control box is color coded and neatly organized. Ethernet plugs and jacks allow us to plug in the tether with ease. The case holds the saber tooth drivers, stepper motor driver, arduino, and raspberry pis (Figure 14).

Figure 14
Main Control Box

Control System

Strain Relief: Topside there are four RJ45 ethernet plugs from the tether wires that connect to the control case with a corresponding female jack (Figure 15). The plugs, if pulled on, will not pull the actual wiring but the control case instead. On the ROV, tether thimbles prevent the strain of soldered connections. When the tether is pulled, the thimbles (Figure 16) will pull on the frame of the ROV rather than the wiring. Strain relief is required so that wires are protected while the ROV is in operation in the water.

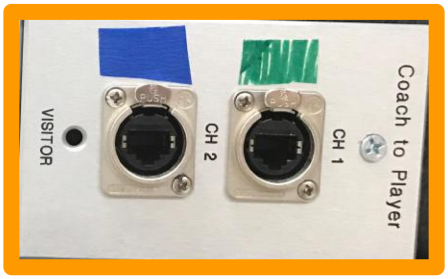


Figure 15
RJ45 jacks

Figure 16
Tether thimbles

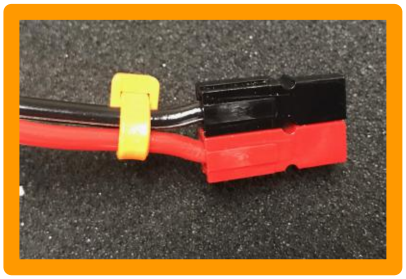


Figure 17
Anderson Power Poles

Anderson Power Poles: To supply power to the ROV, our company uses these plugs. They easily attach to a power supply and our control box (Figure 17).

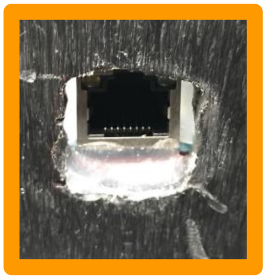


Figure 18
Ethernet Port

Ethernet Ports: To make transportation easier and more organized, our company uses ethernet cables. The ethernet ports are used to connect the smaller control boxes to the main control box (Figure 18).

Control System

Sabertooth Drivers: The saberteeth control the movement motors. They are a type of motor driver that supply the right amount of voltage depending on the position of the joysticks (Figure 20).

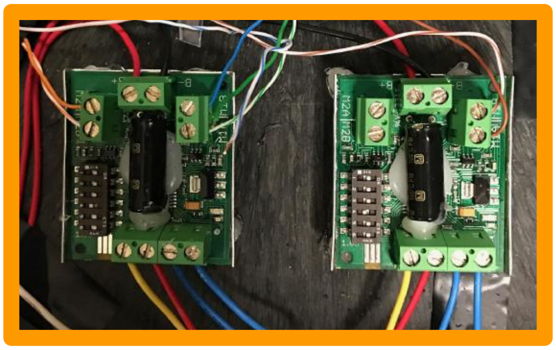


Figure 20
Sabertooth Drivers

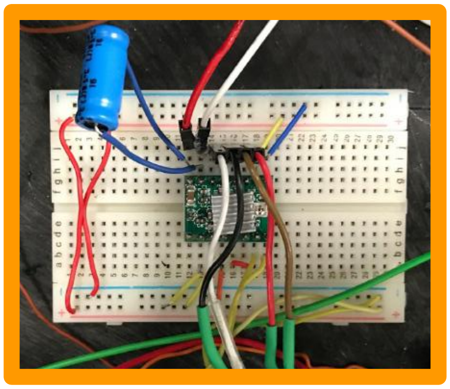


Figure 19
Stepper Motor Driver

Stepper Driver: Our company used a Pololu A4988 Stepper Driver to control the stepper motor for the valve turner (Figure 19).

Raspberry Pis: There are two raspberry pis in the control box case used with the USB plumber cameras. First, our company set up a network to relay information to the monitor. Then, a python based program was used to operate upon the USB plumbers cameras, which was then streamed to the monitor (Figure 21).

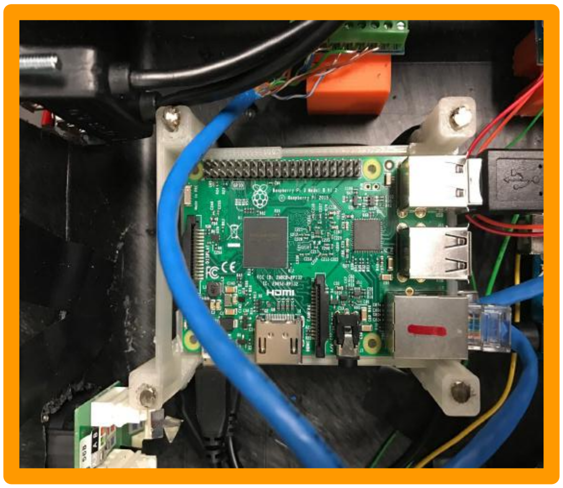


Figure 21
Raspberry Pis

Control System

Arduino UNO: The Arduino controls the stepper motor for the valve turner. It works with two buttons to turn the stepper motor clockwise and counterclockwise. The arduino is located on land (Figure 22).

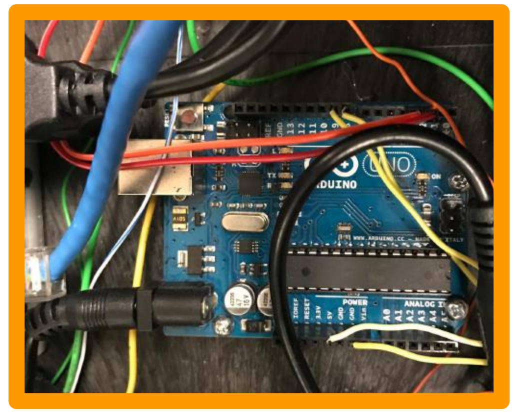


Figure 22
Arduino

Valve Turner and Claw Control Box: The Valve turner uses two buttons: one to turn clockwise, and the other to turn counterclockwise. The Claw uses a switch to open and close. (Figure 23).

Motor Control Box: The motors are controlled using two dual potentiometer joysticks. The left is for vertical movement. The right is for horizontal movement (Figure 24).

Figure 23
Valve Turner and Claw Control Box

Figure 24
Motor Control Box

Control System

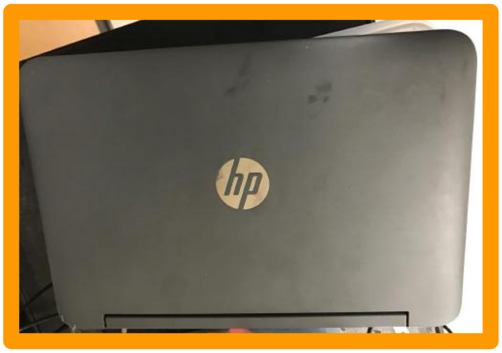


Figure 25
Laptop

Figure 26
Fish Camera Monitor

Figure 27
Monitor

Laptop: The raspberry pi's work with the laptop (Figure 25) to stream to the monitor (Figure 27).

Buoyancy

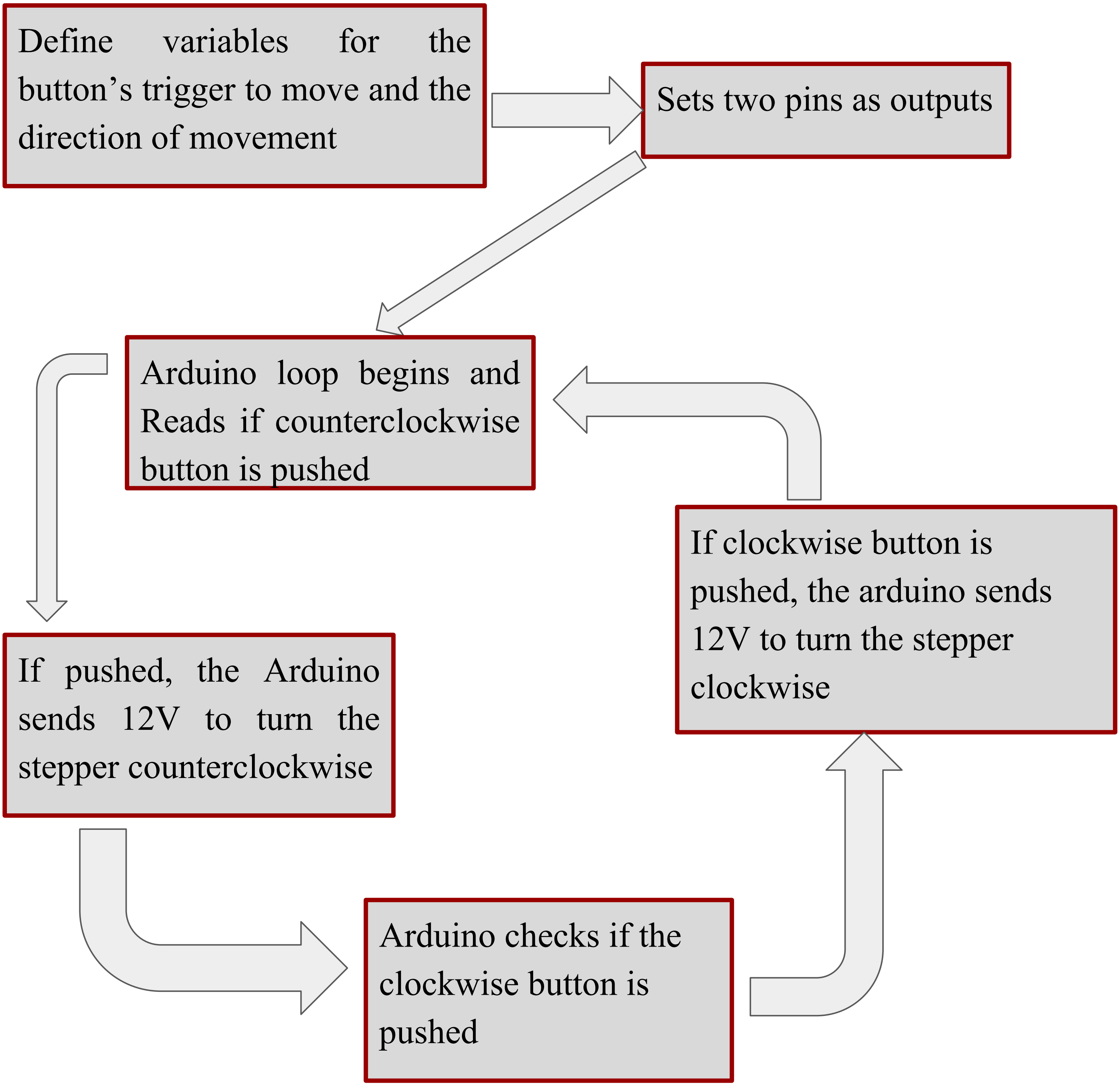
Buoyancy System: The ROV was originally negatively buoyant, and a neutrally buoyant ROV was essential to our company. Four two-inch PVC tubes, each 34 cm long, were applied to maintain such a buoyancy (Figure 28). Chlorine levels vary in different pools, so foam and weights were always available on deck to adjust the buoyancy even further. To ascertain the necessary amount of standard buoyancy, the wet weight of the ROV was determined, weighing 1.8 kg. Then, an equation provided by the Shedd Aquarium allowed our company to calculate the exact requirements:

$$-1.8\text{kg} \times 1000\text{g}/1\text{kg} \times 1\text{cm}/-18.581\text{g} \times \tfrac{1}{4} \approx 34\text{cm}$$

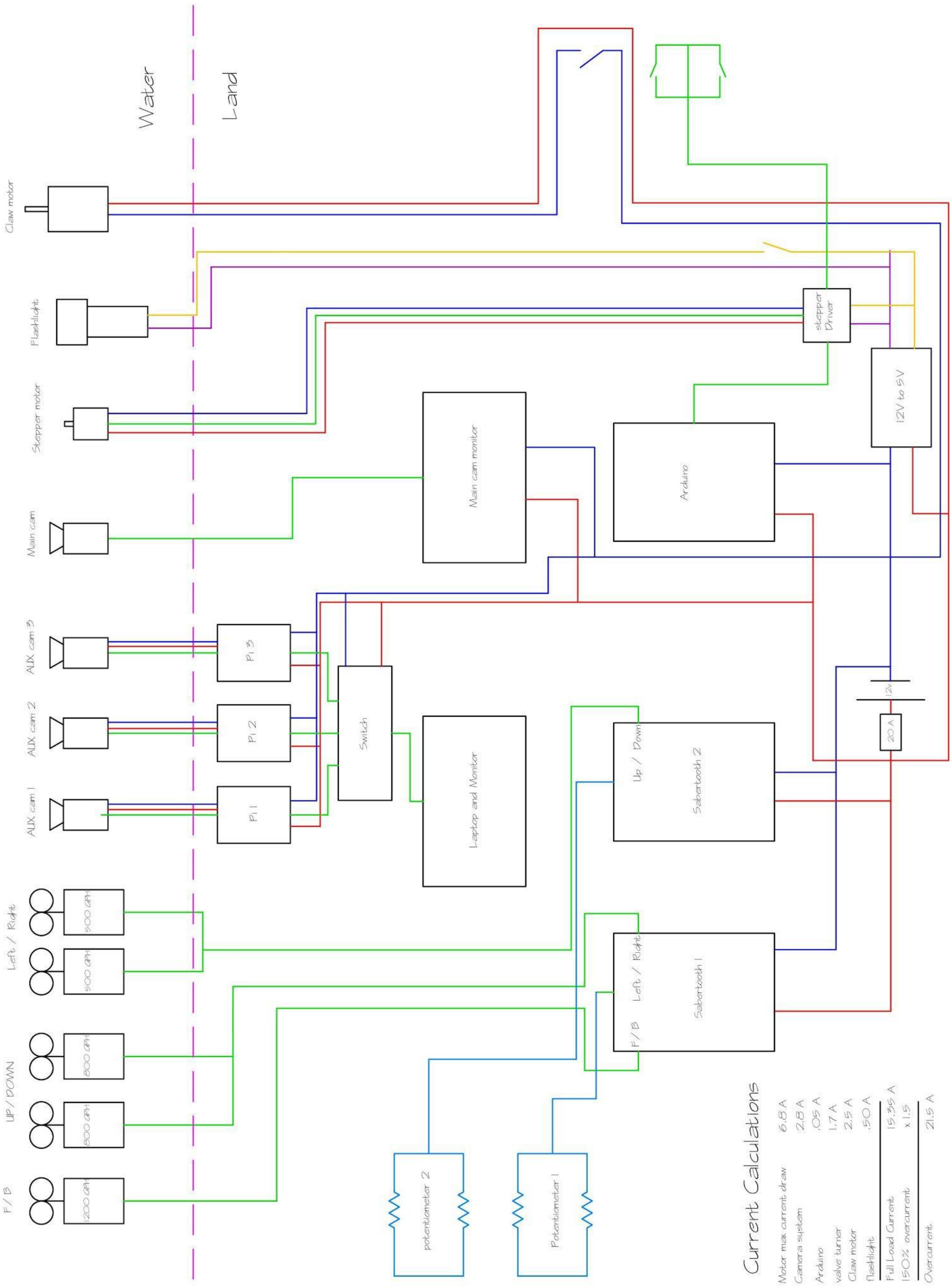
Figure 28
Buoyancy Tube

Software Flowcharts

Arduino Flowchart



System Interconnection Diagram (SID)



Safety in the Workplace: Crusader Robotics regards safety as a top priority. In order to guarantee safety in the workplace, our company follows certain precautions, which were further enhanced through a Job Safety Analysis completed with a representative from the Occupational Safety and Health Administration (OSHA) (Figure 29). By breaking down into job types of electrical, mechanical, and pool work, our company determined some potential hazards in the workplace and what procedures to take while on the job for more effective prevention.

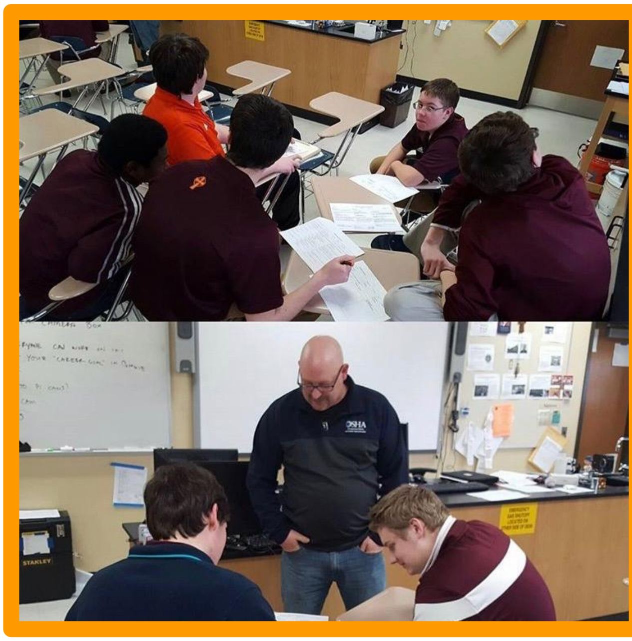


Figure 29
OSHA representative helps team create job safety analysis

Injuries that can take place from electrical work include cuts, electrocution, and burns. To prevent these from happening, our company ensures to use the proper tools, wear proper eye wear, clothes, and gloves, and keep flammable objects as far away as possible. During mechanical work, dangerous tools such as a soldering iron, PVC cutters, a drill, a hot glue gun, scissors, utility knives, wire cutters, staplers, zip ties, a saw, and batteries all pose hazards. To prevent injury from such tools, our company has cleaned tools and stored them away properly, worn protective gear, communicated with other teammates to avoid horseplay, and trained novices how to use tools at the start of the year. Lastly, regarding pool safety, company members are at risk of slipping and falling, tripping on wires, and drowning, for which our company wears the proper gear, maintains organization, tapes down certain parts, keeps vigilant on-duty lifeguards with the proper life-saving necessities, has a mounted power strip, and provides shrouding on motors.

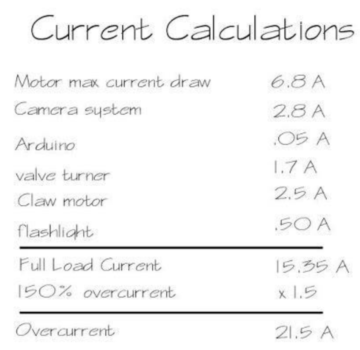
Safety

Figure 30
20 amp fuse

Fuse: Our company uses a 20 amp fuse instead of the required 25 amp fuse because the 20 amp fuse is safer and shuts down as a safety precaution (Figure 30).

Waterproofing: All of the solder connections on the ROV are waterproofed. To do so, solder is first applied, and then hot glue. Lastly, shrink wrap covers the entire wire and more hot glue is placed at the ends (Figure 31).

Figure 31
Waterproof solder connection



Current Calculations

Motor max current draw	6.8 A
Camera system	2.8 A
Arduino	.05 A
valve turner	1.7 A
Claw motor	2.5 A
flashlight	.50 A
Full Load Current	15.35 A
150% overcurrent	x 1.5
Overcurrent	21.5 A

Figure 32
Fuse calculations

Shrouding: The motor shrouding is a custom 3D printed piece that fits over the motors. The piece easily slips into PVC piping like a pipe fitting so it fit perfectly with the frame. A coil allows water to flow both ways through the motor propellers. The shrouding is important because a person, fish, or animal could sustain injuries with a non-shrouded propeller. The shrouding also prevents foreign objects from hitting and damaging the propellers (Figure 33).

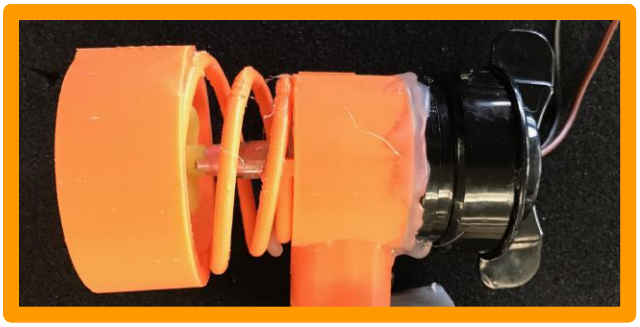


Figure 33
Motor With Shrouding

Testing & Troubleshooting

One of the most preliminary forms of testing involved the design process in engineering. Once ideas were formulated, concepts came together, and a physical model was created, the next step was to test out that model. By then evaluating our innovation, our company improved it to the best of our ability. Once the functional model of Edmund Mk. III was completed, pool runs were begun. At this point, doing tests on a regular basis became a vital part of our company's success. Going back to the fact that our company prioritizes safety, various tests would have to be performed frequently on the ROV to maintain its well-being. Each time the ROV was in operation, tests that are performed beforehand include experimentation on the motors, cameras, valve turner, and claw to ensure full functionality. Overall, it is clear that testing and troubleshooting is incorporated from the first step of the design process all the way until the absolute final product is achieved.

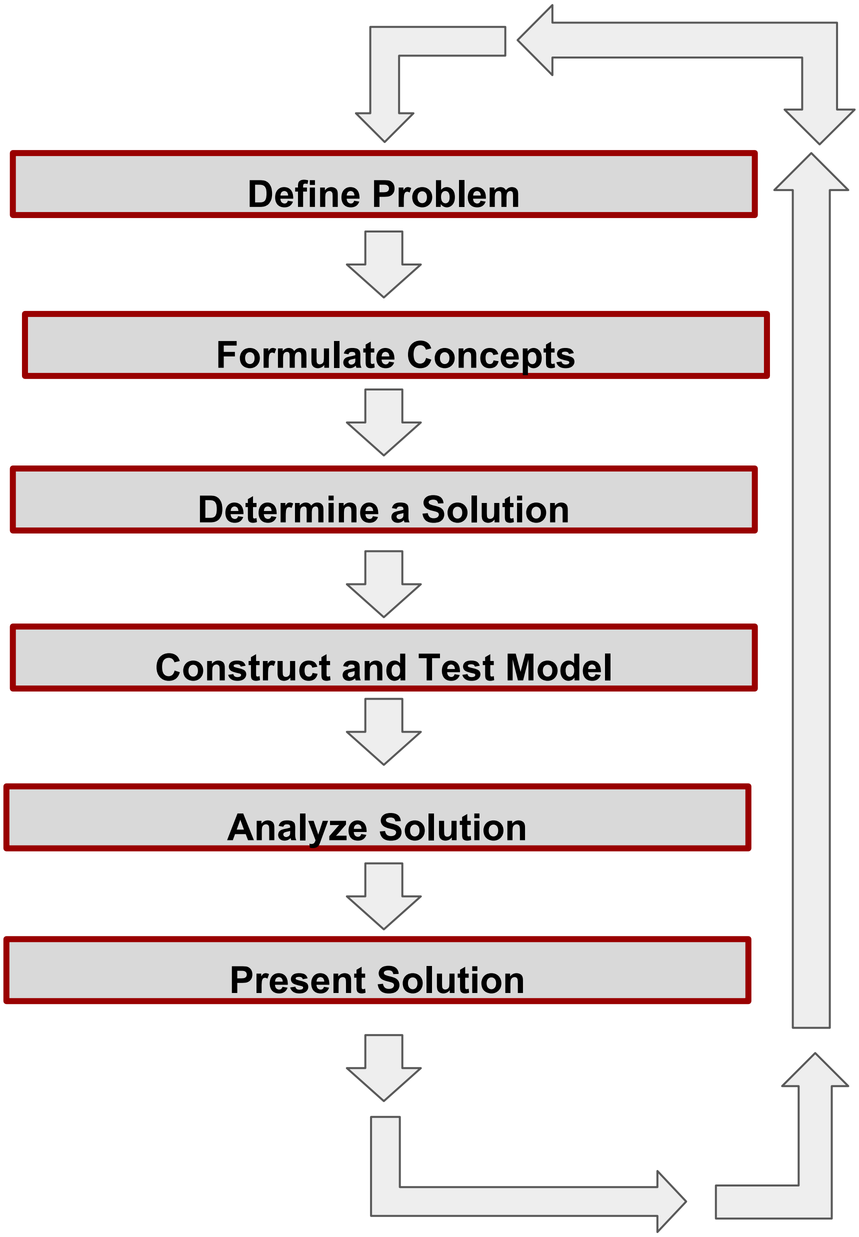


Figure 34
Design Process Flowchart

Budget & Project Costing

Expenditures

Item description	Cost
1200 gph Bilge pump	$24.58
2x 800 gph bilge Pump	$39.52
2x 500 Bilge Pump	$27.46
Monitor	$90.00
Fishing cam	$300.00
Blue robotics Tube	$203.00
Raspberry Pi x3	$112.47
Switch	$25.00
Case	$50.00
Sabertooth x2	$140.00
Arduino	$20.00
Vex claw	$43.73
Aux cameras x3	$30.00
Misc Ace Hardware supplies	$119.92
Misc Menards Supplies	$73.09
Misc Home Depot supplies	$134.89
Misc Electric	$80.63
PVC	$118.89
Total Expenditures	$1,633.18

Available Funds

Monetary Donations	
Total Donations	$4,800.00
Construction Budget	$2,500.00

Travel Costs	
Team Travel	$12,000.00
Team Lodging	$8,000.00
Total Travel Costs	$20,000.00

We chose to budget ourselves so that we could spread our money through the coming years. We acquired our funds through grants and donations from local businesses. Our travel costs were paid for be individual team members.

Pitfalls Encountered

Over the year, our company has encountered a few setbacks. One of the first pitfalls at the beginning of the year involved reorganization of the company. Over the course of the year, six electrical shorts on the stepper motor driver occurred, and replacing the wires that made an impact and increasing safety precautions were the first steps to future prevention. Next, when looking for a model for the claw on the ROV, our company voted for the best option, done similarly when voting on the ROV frame design. A 3D printed claw was chosen due to the fact that such parts were typically a success (Figure 35). However, this part was an exception; the screw and nut would constantly become jammed. As a result, our company

result, our company decided to use a Vex Robotics claw kit. Closer to the date of the Midwest Regional competition, the tube holding the raspberry pi system suffered a leak, which was temporarily clogged by an absorbent material. Fortunately, none of the wiring for the camera was severely damaged. No matter what challenge it was that our company faced, we persevered by always determining a solution.

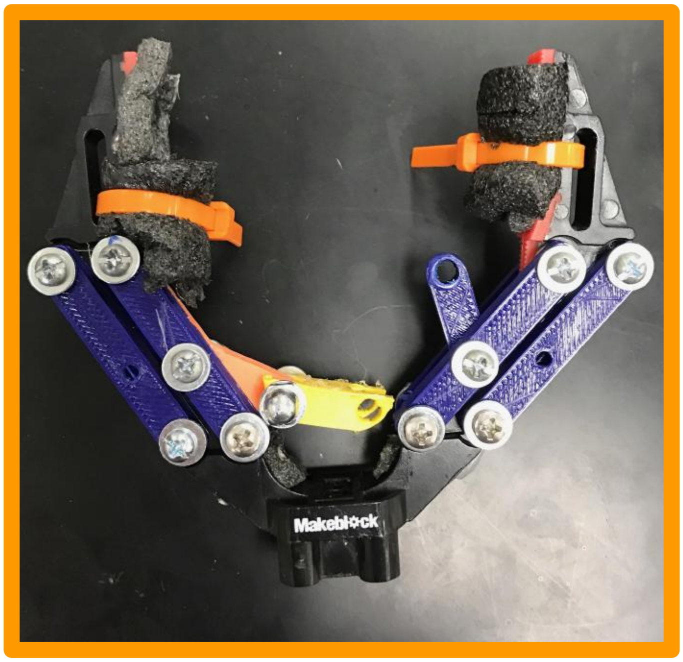


Figure 35
Old Claw

Future Improvements

During the course of the year our company noticed that ROVs traditionally have a standard design. Therefore, the desire to develop a virtually infinite, versatile ROV that could be quickly constructed and deconstructed to fit any project became a goal of future ROV design. Thus, the Research and Development team began a series of independent projects: developing custom 3D printed parts, experimenting with clip-on weights, constructing modification ports, and planning an adaptable, universal controller; all focused on realizing this possibility. Though most of the prototypes never made it into this year's model, Edmund Mk. 3.5, they will be revisited and considered as possibilities for future seasons. Additionally, efforts to improve the overall efficiency of the Crusader Robotics Company have been undertaken and executed, but they are theoretically never complete. Our company will continue to improve our methods and programs for as long as we endure, striving for advancement driven by our passion for improving ourselves and the world.

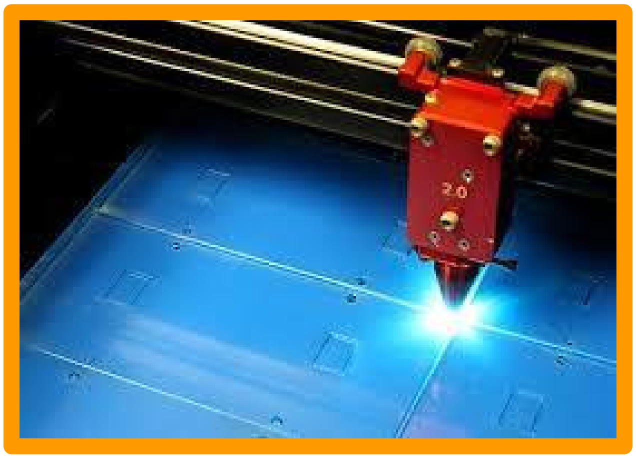


Figure 36
Laser Cutting

Company Evaluation

Crusader Robotics primary goal was to complete every MATE mission task. In this sense, the company has been successful in that the constructed ROV has been able to complete each task in this year's MATE product demonstration. The most rewarding part of the experience for the company was being able to see how separate projects related to the design have come together at the end of the year for an adaptable ROV. Crusader Robotics is proud to say that everyone in the company played a role in making the ROV become what it is. What makes our company the strongest is our organization and determination to solve any problem that comes up without worry or panic. The efficiency of the company could be improved with more focus on the task at hand. Unity is one of the company's most prolific aspects, as most members are friends outside of the robotics lab. However, even if personal relationships outside of practice may not be perfect, everyone who is a part of the company has the mindset that we are all working towards a common purpose: to build a product that can complete tasks for modern port cities under water. What we could do different next year regarding the ROV is to move away from PVC and move towards a custom laser frame. Laser cut pieces would be a better change from PVC because they are more reliable, customizable, and durable.

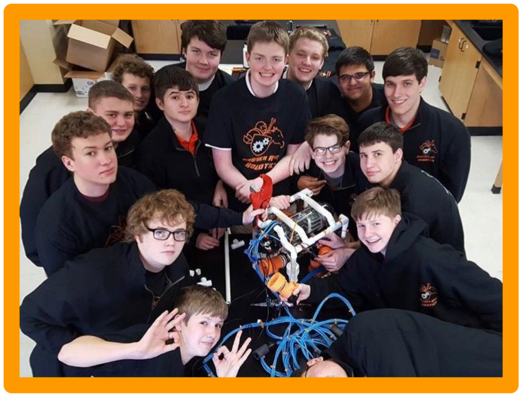


Figure 37
Group Photo with ROV

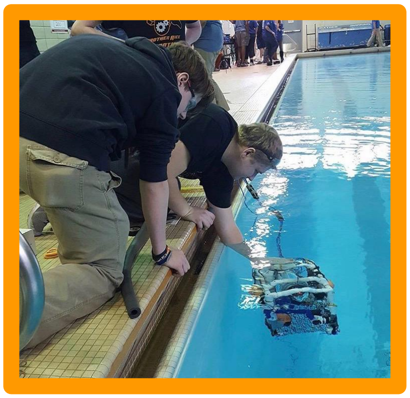


Figure 38
Putting the ROV in the water

Figure 39
Grade School Tournament

Grade School Tournament: At Crusader Robotics' 2nd Annual Grade School tournament, 7th and 8th Grade Students in the area were introduced to the design process throughout the day. At the end of the tournament, they put their own ROVs into the pool and competed for points. The primary goal of the grade school tournament was to encourage junior high students to become interested in robotics.

Mentoring Grade Schoolers: At Clissold Grade School, Crusader Robotics instructed students about the design process and taught them how to use an ROV kit. Like the Grade School Tournament, our company uses the mentoring of grade schoolers about robotics to spark their interest and encourage them to pursue such careers regarding technology in the future.

Figure 40
Crusader Robotics at Clissold Grade School

Photo Credits, References, Acknowledgments

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MATE ROV Competition Ranger Manual

Acknowledgements:
Crusader Robotics would like to thank the Shedd Aquarium, MATE, and all our sponsors for their support this year. We would also like to thank all of the parents who came to support us at the competition. Finally we would like to thank the graduating seniors and our mentors. We couldn't do it without you.

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