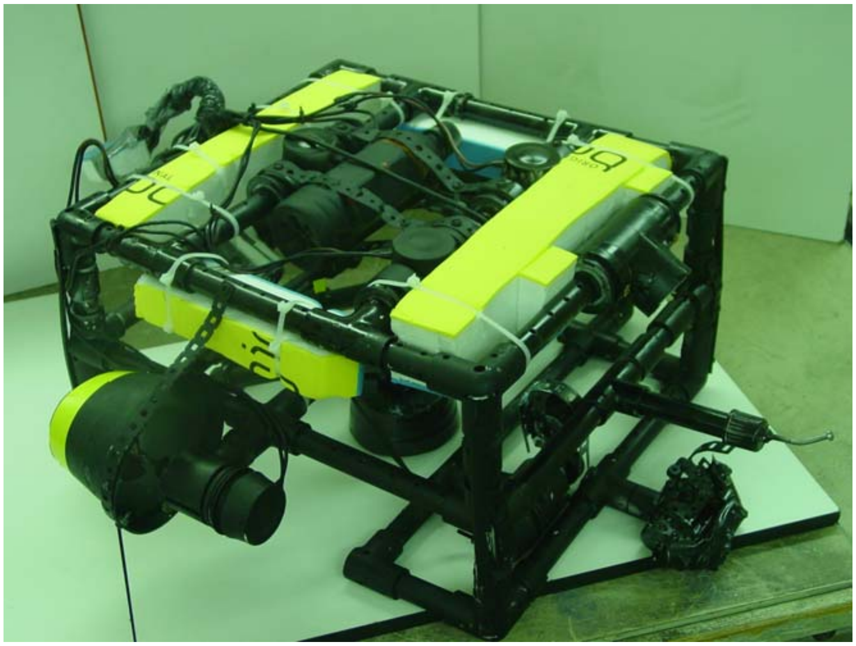
Technical Report



"Paul-E"

Moanalua High School Robotics Team

"IDK"

Team Members:

Julian Cecil	Sophomore
Nina Duong	Sophomore
Andrew Lo	Sophomore
Erik Okamura	Sophomore
Angel Diep	Sophomore
Collin Yabusaki	Sophomore
Hollyann Loui	Freshman

Instructors:

Mr. Randy Sakauye	Underwater Advisor
Mr. Robert Widhalm	Robotics Advisor

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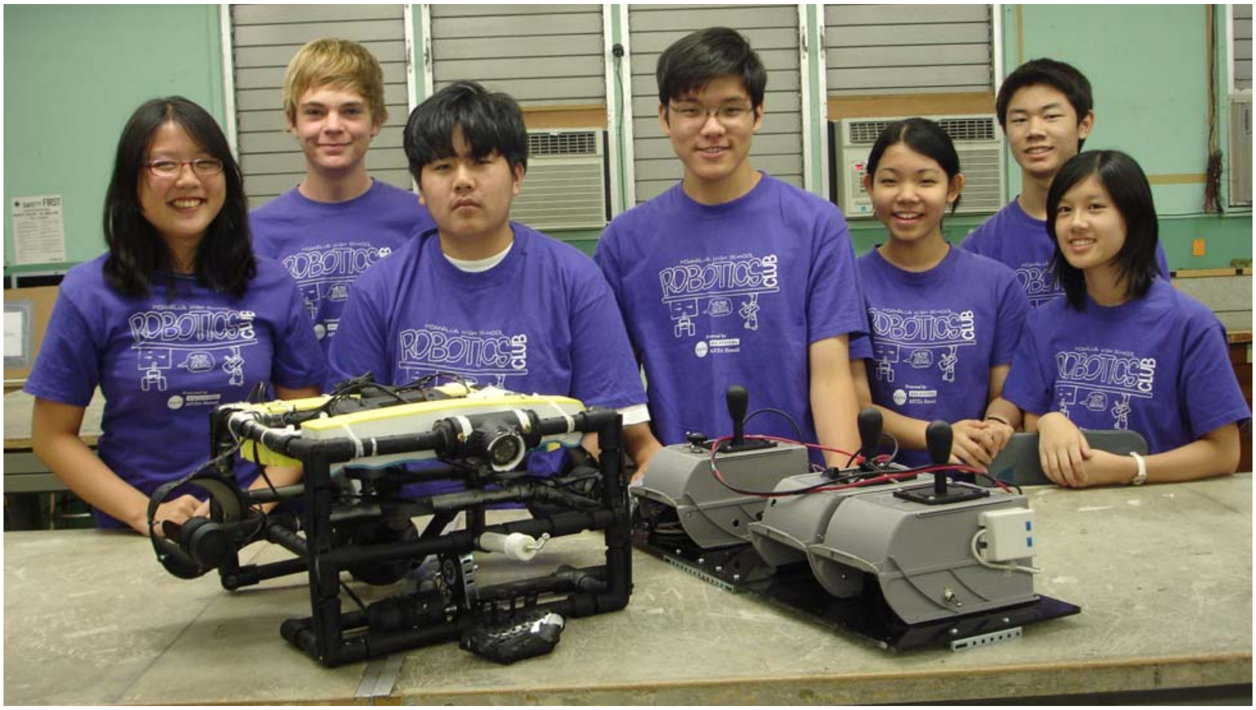
Abstract

Through the 2009 Hawaii Underwater Robotics Competition (HURC) challenges, teams simulate the rescue of the crew of a damaged submarine by completing four missions. Our ROV, Paul-E, was built to complete the four missions vital to a real crew's survival. These missions include inspecting the submarine for damage, transferring survival pods to the submarine, replenishing the submarine's air supply through ventilation, and Remotely Operated Rescue Vehicle (RORV) mating to rescue the crew. In order to accomplish all missions, a ROV that could easily maneuver through the water, identify problems with the submarine, hoist and lower pods, and turn a hatch both ways for locking and unlocking, was constructed. Paul-E has 6 motors, 3 cameras, a skirt (to cover the escape hatch), an arm (to hoist/lower the pods and serve as a utility tool), and an innovative pulley system to fulfill all missions.

Our report illustrates the electrical and structural design of our ROV, challenges that we faced, our troubleshooting techniques, the lessons we learned, future improvements, and acknowledgments. We also include our research on a submarine rescue, as well as references, individual reflections, and photographs of our completed ROV.

Team Organization



(from left to right) Nina Duong, Julian Cecil, Collin Yabusaki, Erik Okamura, Hollyann Loui, Andrew Lo, Angel Diep

This year, with rookies as well as a few experienced members, communication and teamwork were especially important. Each team member contributed specific skills and expertise required for the completion of Paul-E and it was found that only when the whole team was together, did things get done efficiently and accurately. Though each individual was expected to complete their own specific tasks, there came a point where we needed to help each other, allowing us to experience all areas encompassed by HURC. This way, we shared new concepts and were able to become more informed about the constant changes made to our ROV.

We named ourselves “IDK” because we could not agree on a name. Our ROV is named Paul-E because of its special feature, the pulley system.

Captain

Julian Cecil

Documentation

Angel Diep

Nina Duong

Hollyann Loui

Building

Julian Cecil

Erik Okamura

Andrew Lo

Collin Yabusaki

Electronics

Julian Cecil

Andrew Lo

Nina Duong

Design Rationale

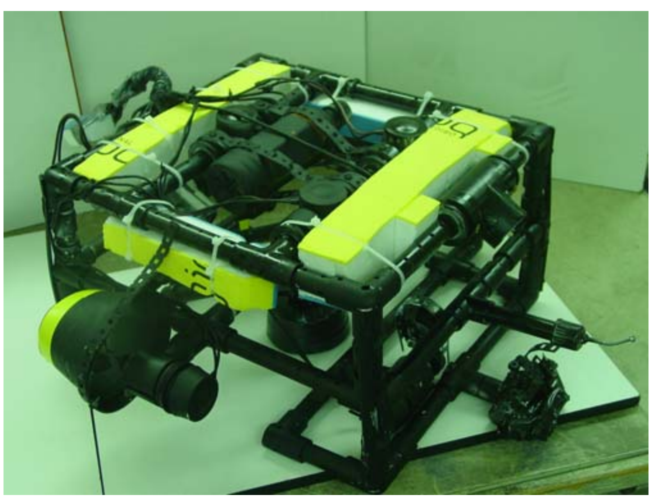


Figure 1: Final ROV

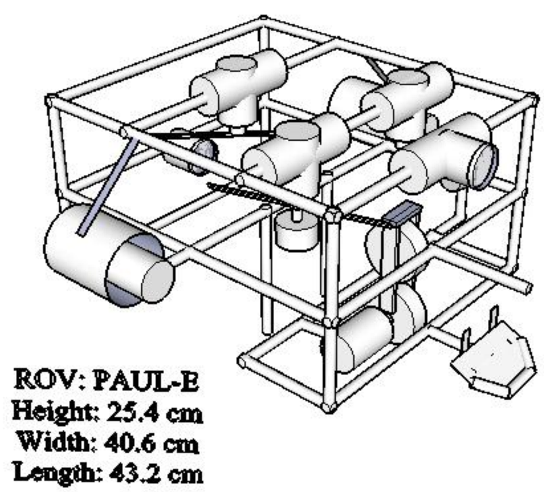
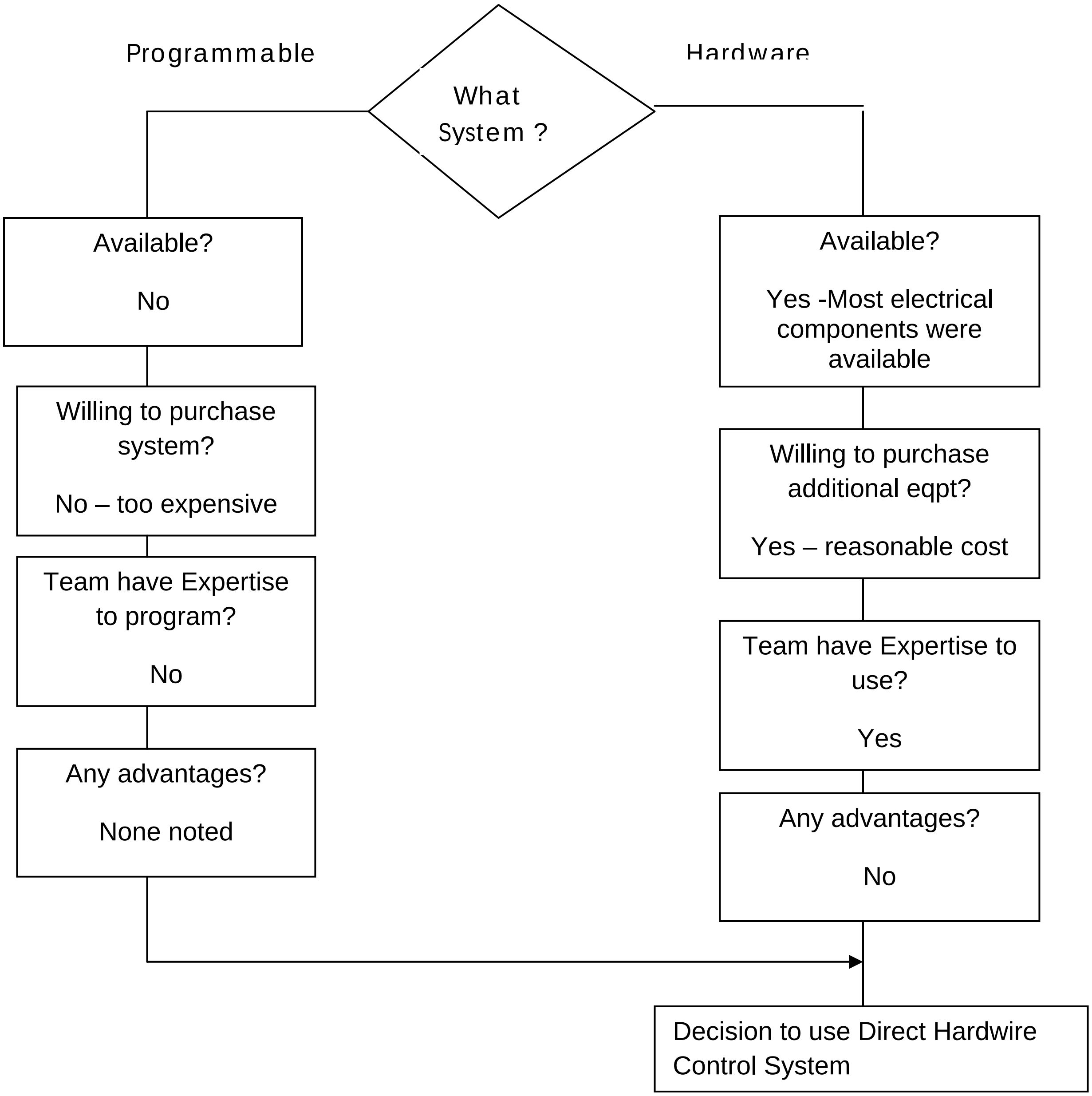


Figure 2: Final CAD Model

Programmable SW Control System vs. Direct Hardwire Control

One of the first decisions we made was whether or not to have a programmable SW control system or a direct hardware control system. Our rationale was as follows:



Frame Construction

Polyvinyl Chloride (PVC) tubes were used as the main building material for Paul-E's frame because of its lightweight, durable, and easy to assemble characteristics. PVC is hollow, making it easy to cut and assemble due to the wide variety of connector pieces available. Using PVC was also very beneficial because it provided maximum flexibility for structural changes, such as repositioning motors, cameras, and other tools to maximize operational efficiency as well as centralize weight distribution. Finally, PVC helped to maintain an open architecture framework (43.2 cm x 40.6 cm x 25.4 cm) to optimize control/mobility by enabling water to flow freely without structural obstruction.

Figure 3: PVC (Polyvinyl Chloride)

Buoyancy

For consistent ballasting, many holes were drilled into the frame of the ROV to avoid air pockets and slow leaking. To offset the sinking, floatation (made from boogie board) was used to balance the ROV and achieve neutral buoyancy at 1.5 meters. In addition, a water bottle was used as a variable buoyancy device to adjust for added weight (ex. air insertion unit) and to fine-tune neutral buoyancy as required.

The amount of floatation and the amount of water in the water bottle were all tested during pool trials to ensure that satisfactory buoyancy was achieved.

Tether

The tether is used to transport power to Paul-E. The current 12.2 meter tether is made of CAT-5 Cable and three camera video links. CAT-5 Cables were chosen due to its lightweight and flexible characteristics. In the CAT-5 Cable, two 22 gauge wires were doubled up to each motor to provide an effective 18.5 gauge wire. This allows for less power loss and greater reliability through redundancy in the event of one wire breaking, the other can still provide power.

Convenience and efficiency are provided through the organized manner in which the tether is connected. The multiple wires are tied together with zip ties and pieces of floatation are added to compensate for tether weight and drag. The CAT-5 Cables were connectorized with RJ45 Connecters to simplify transport and facilitate electrical troubleshooting. Thus, when the construction group requires the ROV and the electronics group requires the control box, they are able to disconnect the tether and work simultaneously.

Propulsion

Propulsion was provided by SHURflo Aerator Cartridges, which was chosen due to its small size (10.8 cm x 5.7 cm), electrical efficiency, and commercial waterproofing characteristics. Currently, 5 motors are used to propel our ROV, providing propulsion equivalent of pumping 38 liters per minute. These motors have low current requirements of 3 amps each and are adaptable to our ROV frame, allowing for ease of installation. There are 3 motors on the top; with 2 in the front and 1 in the back for maximum lift and tilt capacity. The 2 side motors allow for a full circle rotation going both clockwise and counter clockwise. In order to mount the motors in favorable positions, PVC connectors were customized for this purpose. Also, specialized marine propellers were used for the side motors to enhance propulsion efficiency and are housed in 7.6 cm nozzles (made from flower pots) for personnel safety.

Figure 4: Side motor

Figure 5: Customized PVC piece for motor

Visibility (Camera)

The black and white cameras selected were chosen for their high quality video characteristics and water proof capabilities. Each has 9 IR LEDs to operate in environments with poor lighting and also feature high resolution of 420 TVL. They are also commercially waterproofed and rated to operate at depths up to 30 meters. Finally, these cameras are lightweight, small (3.8 cm x 5.1 cm), and require low operating current (1/2 amps) making them ideal for use with our ROV.

3 cameras were secured in various places on the ROV, providing multiple perspectives for mission purposes. A camera located in the front of Paul-E provides a front view for navigation and survival pod visibility. A second camera, positioned to be able to see the pegs and skirt at the bottom of the ROV is located at the very end of the

ROV. The last camera is located in the center for side-viewing for submarine damage and front-viewing for air tube insertion. Customized PVC connecters were used for camera mounting and to enable manual rotation once mounted.

Figure 6: Center camera

Mission Specific Apparatus

Specific apparatus were created for individual missions. First, a skirt is used for the RORV mating. This skirt follows the guidelines provided from the mission specifics and is made up of a cropped flower pot covered in electrical tape. Second, 2 pegs have been created from PVC, assisting in the opening and the closing of the escape hatch. Third, a simple PVC probe was developed for multiple purposes including “hooking” the ELLS survival pods. Finally, a motorized variable speed Pulley System was designed to be able to feed the air insertion tube into the pipe for that mission. This idea is somewhat innovative in that the pulley can rotate clockwise to release the insertion unit as well as rotate counterclockwise to recover the unit. In this manner, multiple attempts can be accommodated and will enable recovery, should the air insertion unit be accidently dropped.

Though not considered mission specific, it should be noted that the motors are specifically located to provide the upmost mobility to facilitate the completion of the four missions. Also, as mentioned before, the cameras are positioned on Paul-E to provide maximum visibility for each mission.

Figure 7: Skirt

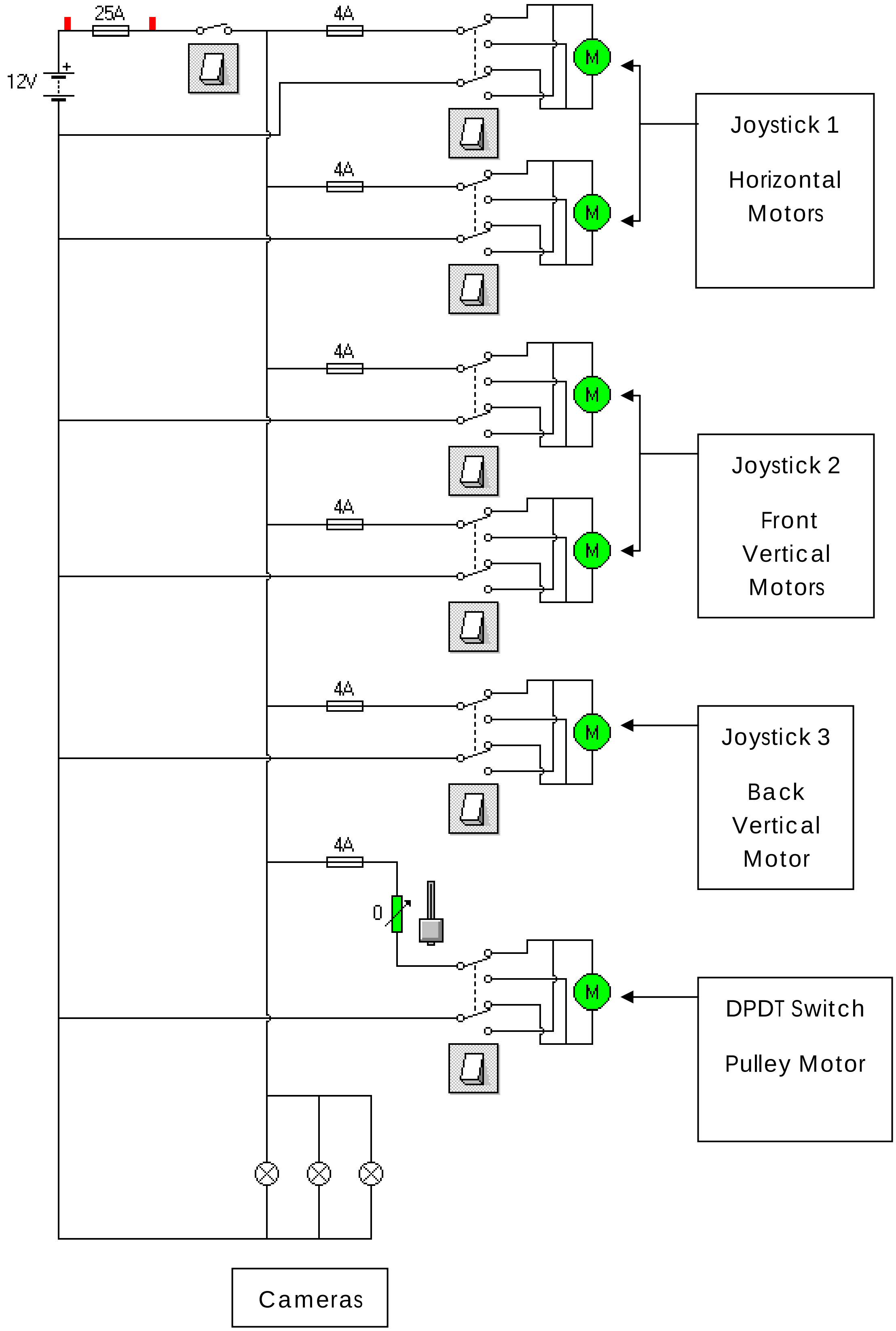
Figure 8: Motorized Pulley System

Control System

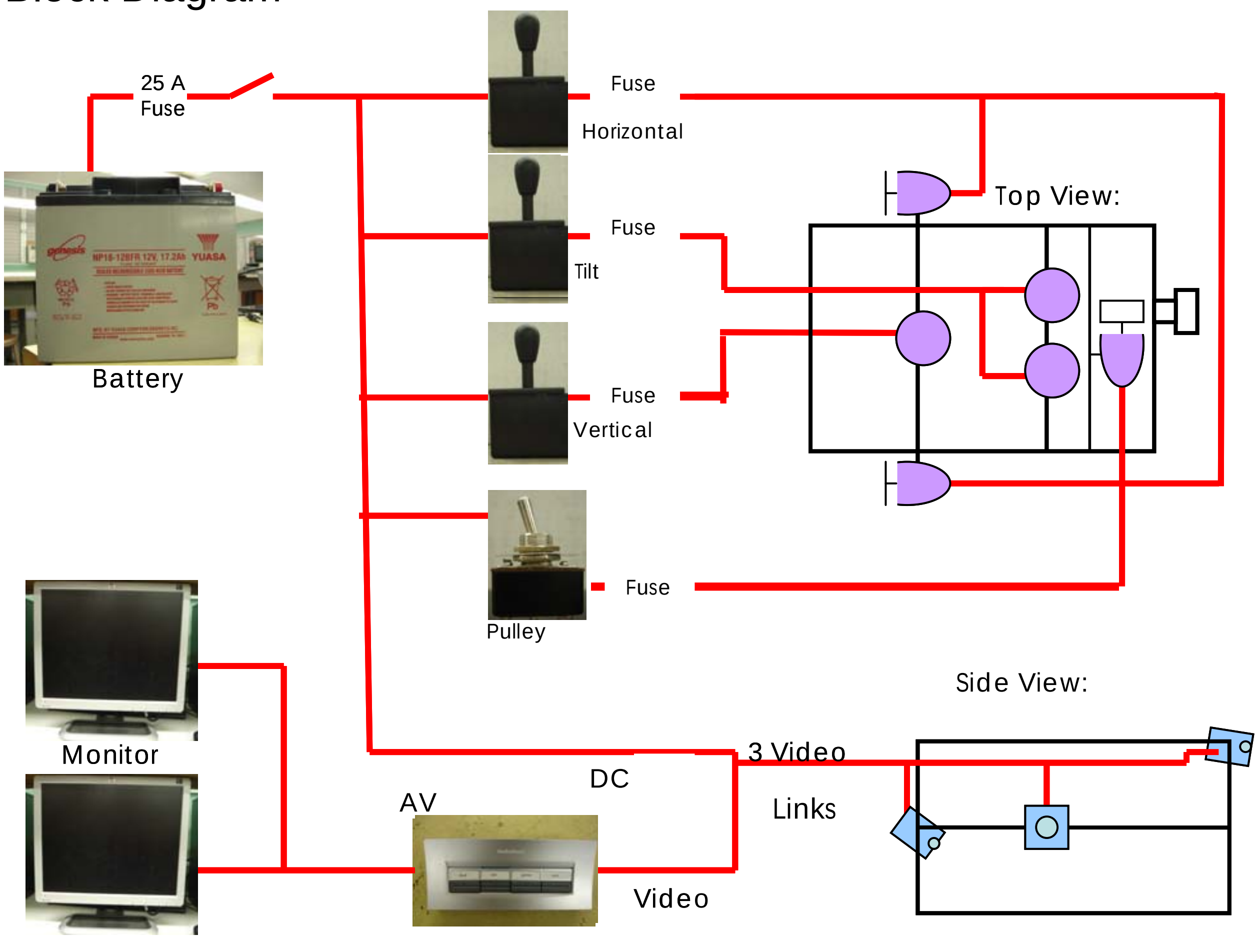
As noted on page 6, we elected to use a simple direct hardware control system. Three joysticks were utilized for controlling the ROV motors. One joystick is for controlling the horizontal movement and the two other joysticks are used to control the vertical and tilt movements of the ROV. Also, a DPDT (double pole double throw) switch is used to control the pulley motor for clockwise and counterclockwise rotation. Each motor is connected to a 4 amp fuse, to protect the ROV in case of any short circuiting. Two paired wires are electrically connected to minimize power loss and provide redundancy reliability, should one wire get damaged. Finally, the electrical linkage to the ROV is connected through RJ45 connectors to facilitate troubleshooting and for convenience.

Figure 9: Controls – Joysticks

Electrical Schematic



Block Diagram



The total peak load on the 12V battery can be summarized as follows:

Components	**Units**	**Total amps**
Motors	6	18 amps
Black & White Cameras	3	1.5 amps
	Total peak current requirements	19.5 amps

Challenges

The challenges we encountered were not only technical, but involved human relations as well. In preparing for this competition, we originally started with three teams, each with four to six members, creating their own ROV. Each team worked independently within their own premise and time availability. As such, some members were not actively participating, or even showing up to work with the team. This made it harder for the remaining team members to follow up on their plans. Eventually, one team dropped out, and the remaining two teams combined to make one team.

Due to this integration, what could be considered the greatest challenge arose. This challenge was transforming the designs of three prototypes into one. The whole team, at one point agreed on the ultimate tools to complete the missions, after much negotiation and discussion. With a limited amount of time to create an integrated prototype, we were on a really tight schedule. On top of that, more than half of our team members were very busy with other extracurricular projects: other robotics competitions as well as academic commitments. Although it was difficult for the whole team to work together at the same time, we didn't let it stop us. While some contributed more than others, we still managed to reach our goal.

Our second challenge was technical in nature. The "new" ROV prototype had mobility problems. We wanted the ROV to be able move concisely in order to efficiently perform the complex missions. Improving performance required a wholesale overhaul of the structural layout and apparatus placement, which in turn required considerable rewiring of the ROV and its control system. While satisfied for now, we envision further fine-tuning as a result of our continuing pool trials.

Troubleshooting

This year, we had many problems with wiring and structure, so we came up with several ways to troubleshoot, some being more extreme solutions than others. The CAT-5 Cable was connectorized (RJ45) in a way that assisted in the isolation of electrical problems. We could easily disable selected circuits and/or detach the tether from the control unit to troubleshoot separately. This allowed us to use the multimeter because the wires were no longer touching through the motor. Since they were no longer touching through the motor we could check for continuity because if there was then we knew we had a short circuit somewhere. We also had many problems with our tether wire because it was CAT-5 and CAT-5 tends to break a lot internally. Even though we doubled up, sometimes we broke multiple wires causing us to have to replace the wire completely. Since we only needed to add a connector instead of rewiring our entire control box it was much easier replacing our tether wires.

We also wired the control box in a manner that ensured all wiring was easily traceable and organized. Not only did this allow for the immediate detection of loose wires and/or other electrical problems, but also eased the rewiring of selected circuits without disrupting the wiring of other circuits within the control box.

Lastly, an open architecture frame was utilized to enable easy access and trouble shooting of each ROV apparatus. Everything attached to Paul-E was readily visible and available, allowing for the immediate change in position and/or trouble isolation as necessary.

Future Improvements

Given additional time, we probably would consider using a fourth vertical motor to add greater tilt movement to the ROV. We also would trial tilting the angle of all motors to see if we can improve overall speed and mobility.

We would further add precision to our structure and remove some of the band aid supports such as VEX pieces and duct tape.

Finally, we would enhance the pulley system to better control the feed of the airline from the tether (through the body of the ROV) to the pulley for release and retraction of the air insertion hose.

Reflections

We enjoyed working together and getting to know each other better at the same time. Being able to joke around boosted our spirits and motivated us in our work. It reminded each and every one of us that we were not alone and that kept us from falling apart. Working on the ROV was not only enjoyable but interesting, as we discovered new ideas and applied them to the ROV.

We all had our own thoughts on improving the ROV and how our team could have been better. One thing that could have been better would be the meeting of deadlines. We also needed to work on meeting and working as a team, and not just parts of the team. We need to avoid procrastinating on what we planned to do or finish.

Many team members agree that we should have had an attendance chart to record who came in to help and work on the ROV, because some people join HURC but they either didn’t show up, or they didn’t contribute much to the team. This is necessary because teamwork is important!

While building the ROV, we learned that we can apply different motors, floatation devices, and other tools. We came up with creative ideas to improve our ROV along the way. Although it took much effort to change and transform the ROV, this put more pressure on us and therefore, pushed us to learn more. After everyone on the team was familiar with building the 1st generation of ROV, rebuilding another ROV was not as hard, but we had to get used to working with the new ideas and applying them to make our ROV more efficient.

Regarding tool usage, many team members learned the correct way to use tools, specifically, soldering techniques. Soldering included, not only the actual soldering of wires, but the cleaning and the preparation of the soldering iron as well. This was important to increase the level of efficiency when trying to connect wires together.

This year was the very first year a CAD drawing (Figure 2) was submitted in the presentation. In creating this CAD drawing, the software, SketchUp was learned and familiarized. The CAD drawing increased the level of professionalism in the presentation, as well as a clean depiction of the ROV itself.

Teamwork played a very important role because everyone felt more confident working together and developing ideas with each other. It was also more of an enjoyable experience to have everyone doing their part and helping others. Although everyone had a specific area in the project to accomplish, we didn’t hesitate to help out another team member with their work.

“As a sophomore and my first year in robotics, my team members taught me a lot and guided me through what was needed to be done. I must’ve asked at least a hundred questions in the process of building the ROV and I’m glad they helped me understand the concepts of the ROV better. Although we had to put a lot of time into building the ROV and wiring it, I felt that it was worth it because it was amazing to see how it worked and functioned underwater.”

-Angel Diep

"This is my second year of doing HURC, and I focused on learning all about electronics. Last year, my first year of HURC, I focused solely on construction. I decided to go into electronics because I wanted to learn something new, and I did. I learned various tasks, ranging from the proper soldering technique to selecting the correct wiring gauge to doubling up to increase the gauge of the wire. But I didn't learn it all overnight. I had to try things and watch them fail over and over again until I finally got it right, and then I would repeat the process for another problem. I put a lot of time and effort into this robot and I enjoyed seeing it work."

– Andrew Lo

“By participating in HURC this year, I learned many new concepts, including skills specifically for HURC and teamwork. Having to create an underwater robot emphasized how important buoyancy and waterproofing was. I feel that this experience was worthwhile because I learned a lot, while having fun.”

-Erik Okamura

Budget/Expense Sheet

Our ROV cost approximately $540. A summary of all the materials and costs are listed below.

Description	Unit Measurement	# of Units	Unit Cost	Subtotal	Cumulative Balance
½" PVC	Linear ft	13.5	$0.25	$3.33	$3.33
½" PVC 3-way 90 deg	# Conn	13	$2.02	$26.26	$29.59
½" PVC T-conn	# Conn	9	$0.38	$3.42	$33.01
1 ¼" x ½" T-conn	# Conn	3	$1.41	$4.23	$37.24
1 ¼" PVC T-conn	# Conn	5	$1.29	$6.45	$43.69
½" PVC L-conn	# Conn	0	$0.43	$0.00	$43.69
½" PVC Cap	# Conn	2	$0.39	$0.78	$44.47
Underwater Camera	# Cameras	3	$80.00	$240.00	$284.47
Piranha motor cartridge	# Motors	6	$23.95	$143.70	$428.17
Arcade Joysticks	# Joysticks	3	$10.95	$32.85	$461.02
Marine Propellers	# Propellers	2	$1.65	$3.30	$464.32
Air Propellers	# Propellers	3	$2.13	$6.39	$470.71
233.52 cm Metal Fastening Strip	Linear ft	1.5	$0.21	$0.32	$471.03
Stem Conn (for props)	# Conn	6	$1.50	$9.00	$480.03
CAT 5 Cable (Tether)	Linear ft	120	$0.12	$14.4	$494.43
25 Amp Fuses	# Fuses	1	$0.80	$0.80	$495.23
4 Amp Fuses	# Fuses	6	$0.99	$5.94	$501.17
RCA 182.88 cm Cable	# Cables	3	$3.95	$11.85	$513.02
Banana Conn	# Conn	2	$0.45	$0.90	$513.92
Power Switch	# Switches	1	$3.95	$3.95	$517.87
RJ45Connector	# Conn	3	$0.50	$1.50	$519.37
BNC/RCA Adapter	# Adapters	3	$2.50	$7.50	$526.87
7.62 cm x 10.16 cm Parts Bins	# Bins	3	$2.24	$6.72	$533.59
Assorted Cable Ties	# Ties	50	$0.02	$0.75	$534.34
Assorted screws/nuts	# Screws/nuts	40	$0.03	$1.00	$535.34
Water Bottles	# bottles	1	$0.05	$0.05	$535.39
Floatation Material	# cubic inches	224	$0.02	$4.42	$539.82

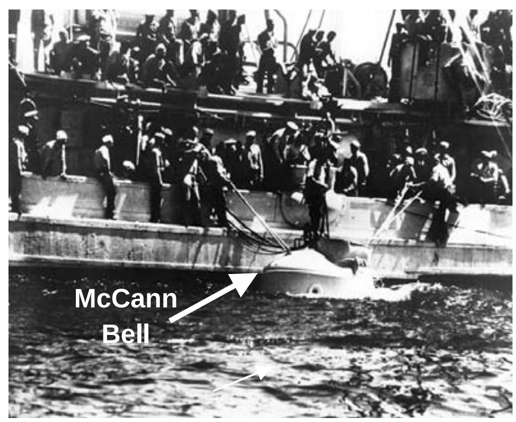
Donations

Whereas all costs were imputed at current value, much of the equipment used were available as surplus, salvage or reuse from previous years. Estimated out-of-pocket costs for this year's ROV is approximately 50% of the total. Consequently Moanalua High School contributed greatly as a donator.

Research – Charles B. Momsen: Squalus (SS-191)

For our research, we selected an individual, Charles B. Momsen, who persevered through naval bureaucracy and traditional thinking to establish a new foundation of submarine safety advancements. Not only had he been able to achieve prestigious ranks in the US Navy (including: Assistant Chief of Naval Operations for Undersea Warfare and Commander of Submarine Forces, U.S. Pacific Fleet), Momsen also received many meritorious awards for his accomplishments (including: Distinguished Service Medal, Navy Cross, Legion of Merit: 2 Gold Stars, and Commendation Ribbon). The most outstanding of his contributions, however, were the multiple innovations and/or prototypes that Momsen designed for submarine safety. These developments have inevitably saved many lives from the great depths of the ocean.

Most noteworthy was an incident on May 23, 1939 where 56 crew members and 3 civilians were on board the USS Squalus (SS-192), a submarine undergoing diving tests in the waters off the Isle of Shoals. Unfortunately, the test dive was not successful in that the main engine air induction valve failed, consequently causing water to enter the engine room. The submarine sank 73.152 m below the surface of the water, leaving 32 crew members and 1 civilian alive and entombed.



At the time of the Squalus incident, undersea rescue below the depth that a diver could operate was unthinkable. Momsen, however, had been working on an old concept of using a tethered diving bell (which dated back to the time of Aristotle) to attach to the rescue hatch of submarines, enabling the trapped seamen to escape and be hauled up to the surface.

Jointly with Lt Commander Allen McCann, Momsen pursued this concept and, as a result, developed the McCann Submarine Rescue Chamber, named after McCann. After multiple testing and prototyping, the final chamber was made of steel, its greatest diameter measuring 2.1336 m and its height measuring 3.048 m. The rescue chamber was divided into a closed upper compartment which contained a reel of 121.92 m of ½ - inch steel wire, as well as an opened lower compartment, which was grooved to easily shape the flat surface of the hatch ring on submerged submarines.

The Squalus would be its first test. After crewmembers spent a night under water, the USS Falcon (ASR-2) rescue ship lowered the McCann Bell. Five trips were made and after a number of entanglements, all survivors were rescued from the Squalus.

Other than the McCann Bell, Momsen also developed the Momsen Lung, which assisted survivors in moderate depths. Previous to the rescue of the Squalus, the submarine S-4 had also suffered a tragedy, but was not as fortunate as the Squalus. All those aboard the S-4 perished. Due to this incident, Momsen began developing the Momsen Lung, which was a bag that recycled exhaled air. The lung contained lime soda, which removed carbon dioxide and replenished oxygen. This device proved successful at a depth of 54.864 m, when a few survivors from the USS Tang (SS-306) were able to escape from the mortally damaged submarine during WWII.

Momsen was clearly a pioneer in emphasizing and developing underwater safety technology during a critical period when submarines were emerging as a mainstay of naval operations. His work and subsequent submarine tragedies paved the way for a more rigorous/formal approach to underwater safety that evolved into programs such as SUBSAFE and ISMERLO (International Submarine Escape and Rescue Liaison Office). New technologies (such as ROV) likewise continue to be developed to protect all who venture into the sea depths.

Though our HURC challenge does not encompass “real” rescue missions as that of the rescue of the Squalus, the idea of safety is of great importance. Multiple safety measures have been listed in this report and implemented in the ROV, in the hopes that we, as “engineers” will never be stuck in similar, threatening situations and can learn from, and possibly enhance, the technology surrounding submarine safety.

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McCann Bell
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http://www.history.navy.mil/photos/images/h97000/h97292.jpg

Momsen Lung
http://www.history.navy.mil/photos/sh-usn/usnsh-s/ss109.htm
http://www.onr.navy.mil/Focus/blowballast/momsen/momsen4.htm

Acknowledgements

- **Mr. Sakauye and Mr. Widhalm**

  For helping us throughout the competition and through our toughest moments. They also provided us with food, supplies, transportation, as well as their valuable time.

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  For allowing us to use their private pool for our pool testing trials.

- **MATE Center**

  For giving us an intellectual and unique challenge that stimulated our thinking.

- **University of Hawaii**

  For sponsoring the HURC competition at the Battleship Missouri Memorial.

- **Battleship Missouri Memorial**

  For hosting the HURC competition.

- **Moanalua High School**

  For providing Lab space for working on our ROV and donating considerable structural material and electrical equipment for this project