Sea tech 4-H Club

Mount Vernon, WA

In Partnership With

Michael Janicki **Peter Janicki** **Madeline Anderson**

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Abstract

The Omega ROV is Sea-Tech 4-H Club's entry into the 2012 International ROV Competition, hosted by the Marine Advanced Technology Education (MATE) Center.

A team comprised of five members designed and built a Remotely Operated Vehicle (ROV) capable of performing the mission tasks published by the MATE Center. The design consists of a versatile aluminum frame which provides support for the many systems on board. Neutral buoyancy and stability underwater are accomplished by a two-part casing. The top half is machined from positively buoyant foam, while the bottom half is machined from aluminum. A removable, mission-specific sled is incorporated into the frame to support a set of tools to accomplish the mission. Four high-quality, 19.1 volt thrusters provide vertical and lateral thrust for the ROV. A pneumatic system operates a manipulator that is used to control or retrieve objects under the water. A set of five cameras consisting of a main one accompanied by four auxiliary ones to provide a comprehensive field of vision. All tooling is controlled by a student-designed electronics system.

The ROV was completely designed and assembled by the team, using student-made custom parts and components, pneumatic systems, sensors, and a limited set of donated parts. The competition theme, "The role of ROV's in exploring WW2 shipwrecks" provided an opportunity for the Omega team to experience the challenges of working in a realistic environment and applying real-world challenges to the design and construction of their machine.

Introduction

Sea Tech 4-H Club has been building ROVs for eleven years, and has participated in the ROV competition sponsored by the Marine Advanced Technology Education (MATE) Center since 2007. The expertise of the members of Omega Inc., as well as the technical and mechanical resources accumulated from years of experience in underwater technology, has allowed Sea Tech to bring an increasing level of sophistication to the MATE competition every year. The 2012 season brought together two teams that as well as having competition experience also shared a desire to learn and create something new.

The team inherited ROV Omega from the previous team where it was designed as an adaptable, versatile, and sophisticated machine, capable of performing a variety of difficult tasks. Once they acquired the mission specs for this year the team went to work on creating and tailoring the ROV to fit the needs and to give the performance desired. The design is tailored to accomplish several specific missions, which are outlined in a Missions Document[1] published by the MATE Center. With this ROV the company has made alterations which they expect to perform exceptionally well at the international competition.

[1] http://materover.org/rov_competition_files/2011/2012_Mission_Tasks_FINAL.pdf

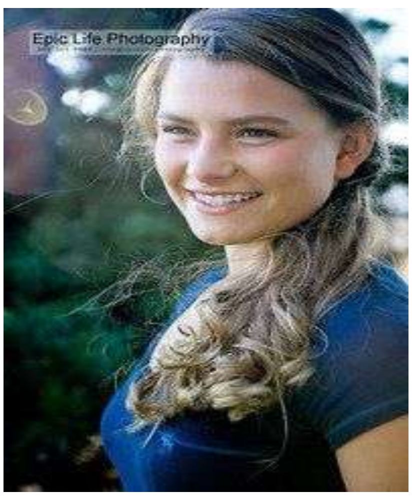
1. The Team

Stanley Janicki

Company Role: CEO

Competition Role: Mission Commander

With six years of building ROVs behind him, Stanley is a focused and hard working individual. Proficient in CAD modeling he created a detailed and accurate model of the ROV. He is currently in eleventh grade as a home-schooled student.



Madeline Anderson

Company Role: Marketing Director

Competition Role: Tether Manager

2012 is Madeline’s first year in participation with the Explorer team. As an active member of the team, Madeline worked on a variety of aspects, though primarily focused on the Technical Report. This is Madeline’s third year in Sea-Tech and is a junior in high school.

Heather McNeil

Company Role: CFO

Competition Role: Manipulator Operator

Heather, is a home –schooled student and the mentor’s daughter. This has given her a unique opportunity to learn about engineering first hand. She is a junior in high school, enjoys math and science, along with their real world applications. This is her fifth year in Sea-Tech and third ROV project.

Michael Janicki

Company Role: Systems Designer

Competition Role: Pilot

Michael is currently a homeschooled freshman in High School. This is his first year participating on the Explorer team. Michael was very involved with the entire building process of the ROV though specializing in the electronics. This is Michaels fifth year in Sea-Tech and his third ROV project.

Sierra McNeil

Company Role: Research and development

Competition role: Mission Specialist

Sierra has participated in Sea-Tech for five years and has worked on five different ROVs. Sierra has been an active member of the team while focusing on the team poster and taking notes. Sierra is currently a home-schooled sophomore.

2. Design Rationale

2.1 Mission Oriented

ROV Omega was designed with the 2012 mission tasks published by the MATE Center in mind. The frame of the machine is versatile, with mounting areas available for additional tooling to be added at any time. In addition to this, a detachable mission sled is included to perform various tasks. A variety of removable, replaceable, mission-specific sensors are mounted to the aluminum frame for collecting and recording data in order to accomplish the mission. Tooling specific to the competition missions include:

- A motorized reel to measure the ship wreck
- A pneumatically-powered gripper to collect and manipulate objects under the water
- A water sampling system
- A set of five cameras for navigation
- A neutron back scanner to survey the wreck

2.2 Design Process

CAD Modeling

In the beginning of this Sea-Tech year the team began the design process with the CAD model and a functional machine from the previous year. They then began tailoring the ROV to fit the challenges and specifications that were going to be asked of it in the 2012 missions.

The company utilized their access to UGS NX6 again for mechanical design. This greatly streamlined the building process, and provided the company with the opportunity to have many of the parts for the ROV cut out on a high-precision water jet or mill. The precision of these parts led to increased sophistication, while still providing complete control over the design of the ROV. Although work on these parts was accomplished at a sponsor facility, team members were heavily involved in the process from start to finish. This allowed several members of the company the opportunity to experience real-world work experience, such as programming a CNC mill.

Utilization of the model was very successful, not only in increasing design efficiency, but in allowing each member to add input to and understand every aspect of the vehicle. To date there are over 100 hours of work put into the CAD model by team members, and it contains nearly 1,000 solid bodies and over 200 part files.

Selection of Parts

The team had a combined experience of over 20 years building ROVs. This experience was highly utilized in the solutions the company chose this year to accomplish the mission tasks. Early this year they chose to re-fit a machine that was technologically sound, yet simplistic in its design to the point where the machine would be extremely reliable and unlikely to fail in any capacity. The technical rationale for the selection of components, as well as the design of the machine, involved a careful planning process and a thorough analysis of every option. This process lent to the stable design of the frame, the reliable outline of a new control system, and the many detailed sub-systems on board, tailored for specific missions. Thorough descriptions of these components are outlined in section *2.3 Mechanical Structure*.

Figure 1 - A CAD model of the Omega ROV

2.3 Mechanical Structure

Frame

The main structure of ROV Omega is a welded frame constructed of 3/16” aluminum. The individual pieces of the frame were cut out on a water jet, then assembled by team members. The work of welding was generously donated by a team sponsor. The frame is specifically designed to accommodate the fairing and the float, as well as to support a variety of subsystems, mission packages, and a set of five cameras. It incorporates a versatile set of mounting holes for potential, future additions. After welding, the frame was anodized to protect the aluminum by making the surface much harder than natural aluminum. The outer dimensions of Omega are 48.5 cm x 66.3 cm x 30cm.

Mission Sled

A process similar to the construction of the frame was used to design and build a mission-specific sled. The sled mounts to the bottom of the frame and is easily removed, and therefore interchangeable, through a set of bolts. It provides a platform for docking and connecting mission tools as needed for any specified missions. The sled contains a V shaped vertical slot on the rear end to temporarily secure the ROV to the bow of the ship while the team reads and determines the length of the simulated shipwreck as outlined in Task #1 of the mission document. The front of the sled provides a convenient mount for Omega's pneumatically operated manipulator.

Figure 2 - The underside of the ROV with the mission sled attached

Stability

The body of the ROV consists of a streamlined, two-part float and fairing system which provides structural rigidity in addition to a strong righting moment. The bottom half of the system was machined on a CNC mill from a solid piece of aluminum, which was later anodized. The top half was machined from high-density polyurethane foam. To compensate for the weight of the frame, the mission sled and tooling, two welded aluminum buoyancy tubes were affixed to the top of the machine. The system of stability establishes the entire ROV as a highly maneuverable working platform which is affected very little by the weight of retrieved objects and by unexpected conditions.

2.4 Payload Tooling

The Missions Document published by the MATE Center outlines a set of specific tasks that must be accomplished by the machine. In order to complete these tasks efficiently, a set of tooling was incorporated into ROV Omega which could perform the mission tasks precisely and quickly.

Figure 3: Manipulator attached to The ROV

Manipulator

The Manipulator is fixed to the front of the mission sled within the view of the forward-facing camera. The design consists of three anodized aluminum gears which directed the individual grippers to open parallel to each other. The manipulator is operated by a pneumatic actuator, which is controlled from the surface by a valve which strokes the actuator in or out fully. The manipulator is attached to the mission sled using a simple receiver type hitch. The team utilized this practical and efficient method by drilling three holes out of opposite sides of an aluminum brace. This connects to the mission sled through a lock and ball spring pin which is pushed through the holes to securing the manipulator assembly to the machine.

Two mission oriented devices are situated on the manipulator. The compass is located on a mount below the manipulator. A neutron backscatter, used as a scanner, is made out of PVC pipe and is securely attached to the side of one of the grippers. Both of these devices are clearly seen by our forward facing camera.

Water Sampling

Mission task #2 according to the mission document, requires a sample of water to be retrieved from the shipwreck. The team constructed a water sampling system that consists of two aluminum rods and an oil tank. The longer rod pumps salt water into the case of the oil tank, while the shorter rod pumps oil out the top of the tank and through a hose in the tether. The displaced oil is then collected by a team member at the surface.

Tooling Alternatives

ROV Omega is equipped with a versatile mission sled, which means that the team is capable of swapping out not only components of the sled, but the sled itself. The other attachments that were devised to assist in the completion of the missions include: The tape measure to measure the length of the ship wreck, the compass to determine the orientation of the ship on the sea floor, a magnate to identify ferrous and non ferrous objects these are all of which are used to help complete mission task#1. To assist in mission task #2 the team has attached a neutron back scanner device in order to look into the oil tank, and a florescent light to illuminate the workspace if needed.

2.5 Propulsion System

ROV Omega is outfitted with a set of four Seabotix thrusters manufactured specifically for ROVs. Each thruster outputs 2.2 kg of thrust. The configuration sets up one thruster on either side of the machine for forward and backward thrust and yaw control. The two vertical thrusters produce ascent, descent, and limited pitch control. The thrusters are equipped with a brushed DC motor, housing, end caps, propellers, and kort nozzles, so no modifications were necessary to integrate the thrusters with the system. They are attached to the ROV by a custom made plate fastened to specifically-designed mounting bars on the frame. This allows for quick removal in the case that repair of modification is necessary.

2.6 Cameras

ROV Omega is equipped with a set of five cameras. A forward facing camera, encased in watertight housing with a dome, is used for navigation. The other four cameras are mission specific cameras for overall view awareness. These auxiliary cameras are gimbal mounted for directional adjustments and each includes a coax power cable that uses a 3 pin connector to provide plug and play operations. All cameras together bestow several views for ease of completing the mission tasks assigned.

Video signals transmitted from the cameras are sent through a 5-line multi coax-cable with BNC connectors inserted in the tether. The camera cable connects to the box which converts the 3-pin, waterproof connector to the BNC- interface box located inside a clear polycarbonate box. Once connected and checked, the box was potted with molten, clear- jelled, candle wax. This wax was used so that the team could observe the connectors after having been potted and is also easily removable for repairs. At the control station end, the 5-line coax-cable terminates into a color quad processor video multiplexer. The quad processor converts multiple video inputs into 1 video output to the control station monitor. The processor provides numerous selectable video display modes. ROV Omega's video system offers detailed situational and visual awareness during the ROV missions.

2.7 Electrical Control System

Control

The Omega ROV embodies a simple design without compromising either proper function or performance. Therefore a hardware-only approach was selected to control the ROV. The team has utilized software to control the machine in the past, and though this approach has some advantages it has often caused unnecessary problems due to the added complexity. The hardware-only approach circumvents these issues by being far simpler and more reliable. The system utilizes two outsourced motor controllers which the team custom-interfaced with the system. These controllers were purchased from Dimension Engineering and chosen because they operate at 48 VDC. The first controller drives the fore, aft and yaw of the machine whereas the second controls the vertical thrusters and the tape measure reel. The controllers utilize 0-5 V analog control signals for the operation. For the first controller S1 controls the speed and direction of two thrusters, and S2 is used to control turning or pitch. The second controller is set so that S1 controls the vertical thrusters and S2 controls the real pitch directly. This control scheme is designed so that when the input is 2.5V the output is set to stop, when the input is set to 5V the output is set to full forward and when the input is set to 0V the output is set to full reverse. The system utilizes a 0-5V hall-effect joystick sourced from ETI Systems to control the X and Y axes of the ROV. Furthermore, potentiometers were used for vertical control. The joystick and one of the potentiometers are mounted to a small, plastic control box, which is itself connected to the main control case by a cable. The main power input is fused with a 25 amp fuse, as well as a large emergency off switch in the case that a quick shut off is necessary. Each individual output is protected by appropriately rated fuses.

Control Case

Figure 11 - Team members testing the ROV for buoyancy

The control system is mounted inside of a single pelican case. A single flat panel, glare-resistant monitor is permanently mounted on the inside of the lid of the case protecting the monitor inside. The main body of the control case consists of a multi-level, three panel assembly that can be removed from the case simply by pulling out two screws. The main, and bottom panel houses the main electrical components; The middle plate which holds the three panels together, is securely fastened to the case, and is shelled providing easy access to the electrical components below it. The top face panel moves about two sturdy hinges on the back allowing for easy access. Along with being organized the top face panel of the case accommodates an emergency off switch for safety, as well as a set of military-grade bulkhead connectors which connect the control system to the tether and the joystick control box. The systems within the control box were built independently so if one component fails, the entire system will not go down; and if a component does fail, due to the thoughtful design it is an effortless fix.

Connectors

The tether is terminated on both ends with high grade connectors. The surface end of the tether is split into two military-grade connectors. A 12 pin connector supplies power to the ROV. An 8 pin connector supplies power to the cameras and lights. On the ROV side, the tether is split into a 12 pin Sea-Con connector for power and an 8 pin Sea-Con connector. To ensure a watertight connection, the Sea-Con connectors were equipped with underwater cable terminations. This process was performed by the team. On the four compact cameras the team utilized 3 pin Cooper Interconnect connectors. These connectors were tested by Cooper to see if they would work for the teams needs.

2.8 Safety Features

Safety was an important consideration for the company throughout the design and building process. Several safety features incorporated into the design of the ROV:

- All thrusters are protected by guards and ducts
- Warning labels are placed near any moving parts
- Handles are incorporated into the frame for safe launch and retrieval
- A safety protocol is always followed during all testing

- An emergency shutoff switch is incorporated into the electronic controls in case of a system failure

3. Expenditure Summary

The following is a summary of the project expenses due to modifications for this year. While the company has created a detailed budget sheet, for the sake of space in this report it has been condensed to a price for each broad category. A more detailed budget sheet can be found in **Appendix A**.

Category:	**Total cost:**	**Donated Amount:**	**Company Expense:**
Cameras	$387.65	$0	$387.65
Tether	$271.75	$0	$271.75
Control Console	$528.13	$150.00	$378.13
Manipulator/ Mission sled	$544.59	$400.00	$144.95
Grand Total:	**$1,732.12**	**$550.00**	**$1,182.12**

4. Troubleshooting

Troubleshooting is an inevitable process when testing a new design. The team utilized the process of troubleshooting many times throughout the year, especially when the outcome of a design was unplanned. Every problem was approached with a careful analysis of all the possible reasons the problem might have occurred, followed by a methodical testing to narrow down the source of the problem.

For example, when the ROV's main camera was first connected the team could not receive a video signal from the main cameras but all of the other cameras still functioned. The team then methodically made a list of different reasons the camera wouldn't work. One possible reason was that the camera was not receiving power. Another was that the camera itself was not functioning. The third was that there was a bad or reversed connection somewhere in the tether or control system. The first two problems were the easiest to put on trial. The camera was removed and the team checked to make sure that power was being supplied to it. Knowing that power was available the team then tested just the camera. To test the cameras itself, the team disconnected one from the system and plugged it directly into the monitor. When displayed on the screen, it was clear that the problem had been narrowed down to a bad camera. The camera was replaced and the camera signal then worked perfectly.

This is just one example of successful troubleshooting applied to the Omega ROV. Similar techniques were applied to the system of buoyancy, and the control system.

5. Challenges Faced

5.1 Anodizing Timeframe

The team carefully compiled a list of the parts needed to be anodized and had it ready by the assigned due dates. However they were faced with the challenge of having to accommodate a company who took more time than was expected and planned for to process their order. This set the team back a few weeks, and recovery was difficult. The team in the future will plan for such delays, and for the remainder of the year they were careful to provide adequate cushion time in order to prevent another setback.

5.2 Team Compatibility

The 2012 team was composed of two members from the original Omega team and in three additional members from a previous team. This brought many challenges and benefits alike. One of the challenges being the newly added team members were accustomed to working in the Ranger class division and had to adapt to the higher expectations of the collegiate team. There were also additional challenges that came from the team having to learn to work together. Overall the team pushed through every challenge to create a hard working, functioning team.

6. Lessons Learned

6.1 Connectors

In past years, Sea-Tech teams have experienced difficulty fitting all the electronics into the designed spaces. This year the team modeled the control box all using the CAD modeling program which enabled them to make sure the electronics and other tools associated with the control box. The main issue was successfully averted using this technique though in the future a priority to complete the process of assembly to be sure everything can be easily put into place, before it is completed.

6.2 Interpersonal Communications

As with any project of this magnitude, communication between team members was indispensable. In order to complete the project on time, it was apparent that the team's method of communication must be prompt, open, and direct. In order to accomplish this goal, e-mail communications between the team included all members as well as the team mentor. To coordinate meeting times, all team members were contacted not only by e-mail, but also by text and phone call. To ensure that each team member knew their responsibilities, a 'To Do' list coupled with personal assignments was updated every week.

The team learned that these communication methods promoted a strong sense of teamwork, ensuring that every aspect of the project was completed with promptness as well as camaraderie. These methods greatly strengthened the communication skills of each individual member, as well as the company as a whole, and the team will be sure to utilize these methods of success on future projects.

7. Future Improvement

7.1 Control System

The company considers the incorporation of a surface-side electronics system to be a success. The idea is not a novel one for the company; it was incorporated into the Omega machine after a careful analysis of previous company machines and utilized the most effective components. The company strongly believes that, although new and improved technology is important, industry standard exists for a reason. The machine incorporates time-tested ideas without compromising technology, and the surface side control system allowed the company to explore a variety of tooling options without modifying the design of the frame. However, the team found that having the control system surface side caused some inconveniences to arise, such as the fact that due to the thruster power running down the main tether the company was forced to add an auxiliary camera tether to prevent signal interference. Having the control system onboard would eliminate such inconveniences along with many others. The main reason the company decided not to do this previously was the space requirements and the overall added complexity. Although it would take much time and effort the company plans on making such changes in order to further increase the usefulness of the ROV.

7.2 Other Improvements

The company would like to accomplish several other improvements in order to improve the ROVs capability for competition, as well as for its use in a real-world environment. These include, installing a hydrophone, creating additional payload tooling, and increasing the tether length. These improvements will allow the company to perform a large amount of precise tasks with the machine, as well as to utilize the machine for educational purposes.

8. Teamwork

A project as successful as the Omega ROV could never have been successfully refit without the level of teamwork that the company demonstrated throughout the design, building, and testing processes. The Omega team is a shining example of a high level of group contribution, time investment, and dedication, as well as an intelligent process to facilitate the planning and creation of the vehicle's technology. The most important contributor to making this team effort a success was the fact that the machine was entirely refit by the team, with very little input from outside sources and minimal mentor participation. With a high level of competition at the international level, it was important for each team member to possess a thorough knowledge of the workings of the machine. In order to accomplish this, every component of the ROV, including the electrical system, was studied and worked on by members of the Omega team.

To facilitate the details of the process, it was important that the company develop and implement a detailed schedule to assist in building the vehicle. This schedule was coupled with individual assignments so that there was no overlap in the work done by the team members. The assignments also ensured that each team member was aware of their individual responsibilities, and that no work was left undone. The assignment sheet was updated weekly as tasks were completed. The technical report, an important component of the MATE competition, was created utilizing individual input from each team member's area of expertise. The implementation of the schedule and assignment sheets caused the ROV to be completed in budget and on time, in spite of many obstacles that the team faced throughout the year.

9. WWII shipwreck: SS Montebello

SS Montebello

On December 22, 1941, approximately two weeks after the Pearl Harbor disaster, the SS Montebello an oil tanker, set out from Port San Luis California bound for a refinery in Canada with over four million gallons of fresh crude. Just five miles off the California's Central Coast a young lookout spotted a dark outline of a Japanese submarine headed for the oil tanker. The men saw a small spark in the dawn's early light, followed by an explosion as a torpedo hit the bow of the 440-foot ship. The men were jolted from their sleep and scrambled for the lifeboats, all 38 crew members survived.

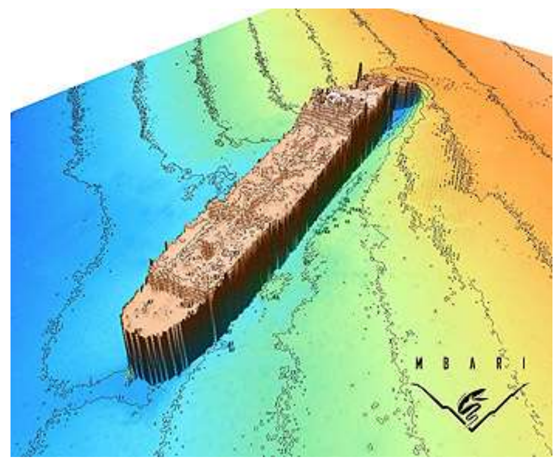
Few knew about the Montebello's fate, even immediately after it sank. Fearing a mass panic that the Japanese had gotten so close to shore, the government confiscated newspaper reports about the sinking at the time and did not publicly disclose the event even into the Cold War.

In 1996 the SS Montebello became a concern when local efforts to memorialize the sinking led to a survey which located the wreck and discovered it was mostly intact, particularly the cargo holds. To their surprise they found the boat sitting upright on the seafloor with the most damage being the bow torn off by the torpedo. Many presumptions that oil was still inside led to worries that a rupture could threaten the nearby Monterey Bay National Marine Sanctuary, but due to the depth, recovery was unlikely and only monitoring continued.

It wasn’t until 2009, when state Sen. Sam Blakeslee R-San Luis Obispo, assembled a team of federal and state officials and scientists to investigate the situation, after learning about the potential environmental disaster from a local newspaper report about the Montebello.

The terrible incident in the Gulf of Mexico last year, galvanized all the stakeholders to take action and be proactive and get answers given the terrible cost and environmental damage that occurred. The SS Montebello project, to retrieve the oil, will cost $2.3 million which will come out of a fund that oil companies pay into for such measures.

Divers along with a remotely operated underwater vehicle (ROV) will begin an assessment to take samples, a process that is expected to take as many as 12 days. Officials have videos and photos from previous dives, but this is the first time technological advancements will allow them to recover oil samples from the tanks which has been said to have the consistency of peanut butter after sitting on the ocean floor 900 feet below the surface in 40 degree water for 70 years.



Sonar scanning of the wreck

1) http://www.huffingtonpost.com/2011/10/11/montebello-mission-california-japanese-sank_n_1004858.html

2) http://abclocal.go.com/kgo/story?section=news/assignment_7&id=6785550

3) http://www.opentheoceans.com/news.htm

4) http://materover.org/main/index.php

Reflections

The ROV Omega project has presented a set of unique, offbeat, and rewarding challenges from start to finish. Our team has refitted a machine capable of performing a diverse range of tasks. It is reliable, highly maneuverable, and very adaptable. With careful planning, we have met every obstacle with intelligent solutions conceived by experience and innovation. The many facets of this project have brought our team closer, forming a group of individuals into a unified team with purpose.

Individual team members have learned to take ownership of various aspects of the project and see them through to completion. As a group, we have discovered that we are capable of accomplishing a project of this magnitude in spite of the challenges. Because of demanding time constraints, we have learned to improvise when the ideal solution was not attainable. We have been challenged with teamwork, frequently facing differences of opinions, but we have learned to rise above these differences, contributing as a unit to a purpose greater than individual self. No task was insignificant, because each part of the process relied on all of the other parts. The team learned to recognize this fact, as well as gain a strong sense of capability.

The competition missions published by the MATE Center have inspired us to create greater things. Without the technical specifications and thought-provoking ideas published by the MATE Center, many of the innovations on ROV Omega would never have been considered. The retrieval system, creative solutions for power, measurement, and the unique manipulation system are all components that would likely never have been conceived apart from the MATE competition. We believe that the design innovations on ROV Omega will set a new standard at the regional and international levels of competition. The product of experience, the vehicle has built us up as competitors, as designers, and as friends. We are very glad for the experience.

11. Acknowledgements

Omega Inc. would like to recognize the companies, organizations, and individuals who made this project possible. Without their support, ROV Omega would never have been completed:

- Lee McNeil, our team mentor, for your constant expertise and guidance. You have taught us so much, and we would never be who we are today without you.

- The MATE Center. Your competition has challenged us to create greater things. Thank you for your inspiration.

- Janicki Industries, for your generous sponsorship of our project through monetary contributions. Your donations of supplies and services were indispensable, most notable the water jetting and milling services, which allowed us to expand our scope of technology.

- Outland Technology, for the donation of our tether.

- Mecco, Inc. for contributing time and expert advice.

- The Skagit County 4-H Office, for your continued support of our endeavors.

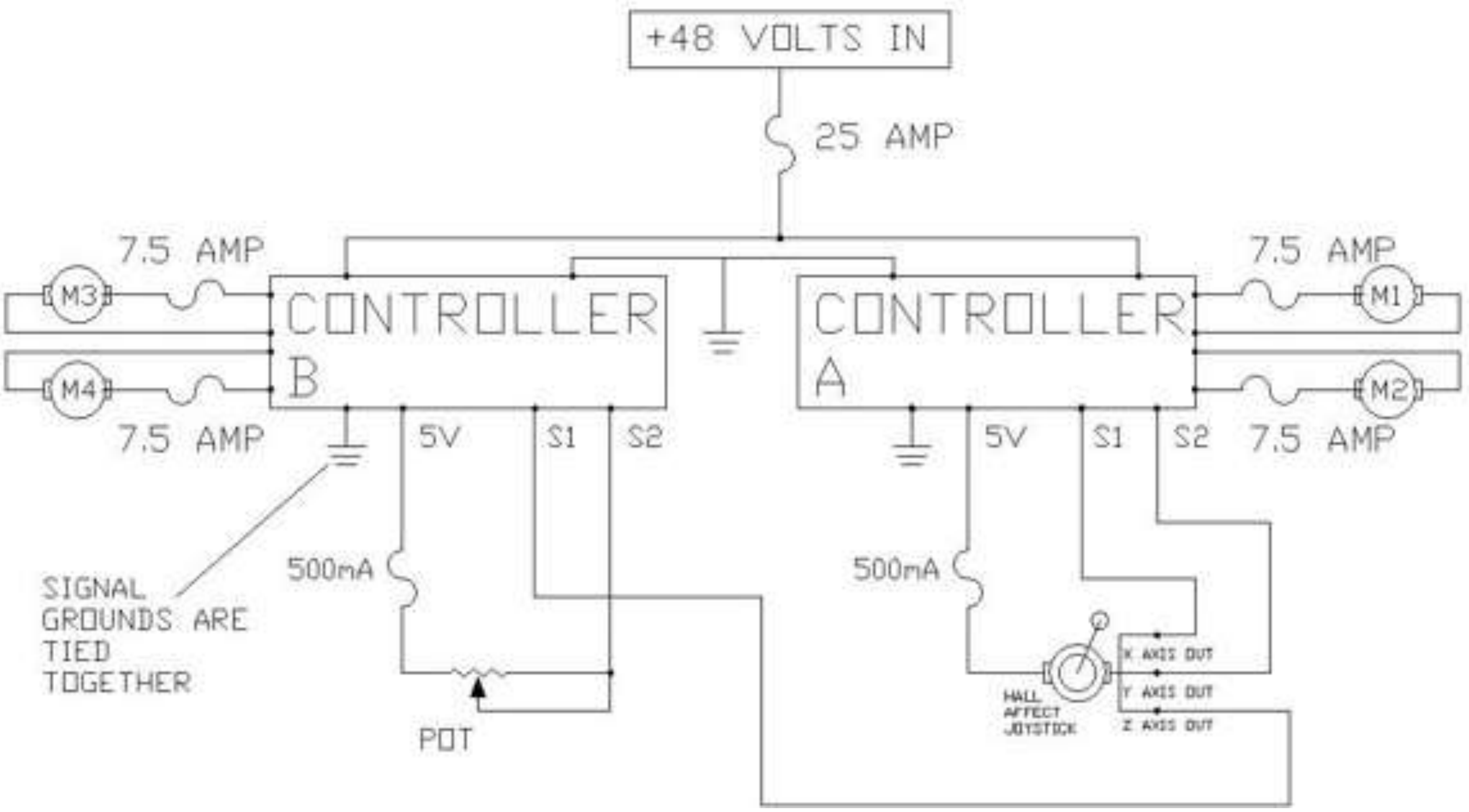
12. Appendix

Appendix A: Detailed Budget Sheet

Donations in italics type

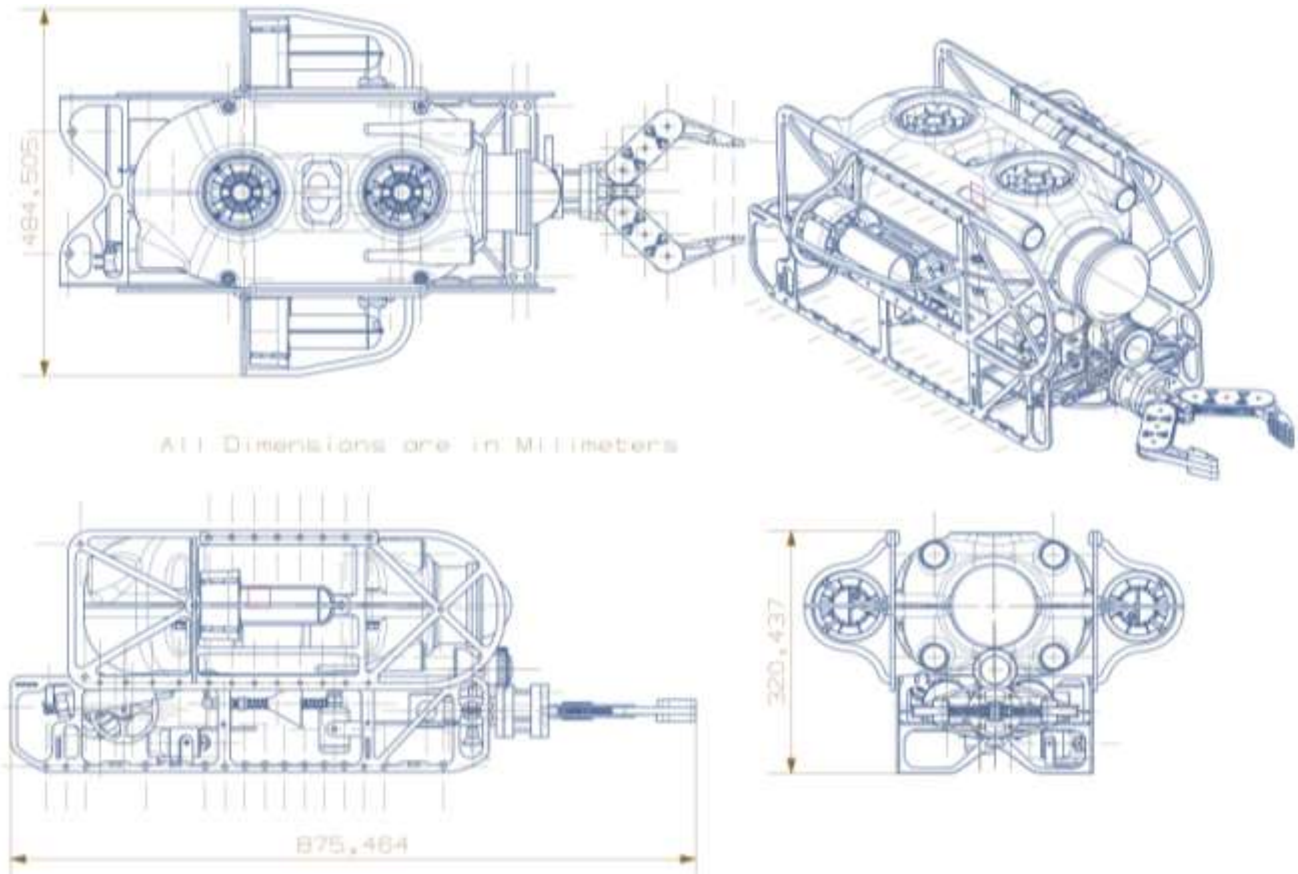
Item:	Qty:	Item Description:	Mfg. P/N:		Source:	Cost:	Total:
Cameras							
1	1	Wide angle board camera 46	PC823XS		Super Circuits	$79.99	$79.99
2	4	380 line board camera	PC303XS		Super Circuits	$39.99	$159.96
3	2	10-32 SS Rivnut	#98005A150		McMaster Carr	$14.42	$28.84
4	2	10-32 SS Thumb Screw	#99607A167		McMaster Carr	$10.97	$21.94
5	2	#10 SS Serated Washer	#91812A427		McMaster Carr	$7.89	$15.78
6	5	3/8" NPT Cord Grip	#2638		Dell City Electric	$0.96	$4.80
7	1	Urethane Potting componnd			AeroMarine	$38.00	$38.00
8	1	Clear Lexan Box	#7092K12		McMaster Carr	$22.19	$22.19
9	5	BNC Solder Bulkhead	#512-1276		Allied Electronics	$3.23	$16.15
							$387.65
Tether							
1	5	BNC to BNC coupler	#70000454		Allied Electronics	$3.95	$19.75
2	2	5 line BNC coaxial cable	#CTL5B-50B		L-Com	$126.00	$252.00
							$271.75
Control Console							
1	5	BNC bulkhead fittings			Skagit Whatcom Ele	$4.99	$24.95
2	5	1' Foot BNC jumper cables			Showmecables.com	$2.75	$13.75
3	5	Right angle BNC adapters			Showmecables.com	$2.87	$14.35
4	1	19" insignia monitor	#19E430A10		Ebay	$152.00	$152.00
5	1	Quad Color Processor	#VM-Q401A		CCTV camera pros	$129.99	$129.99
6	1	.08" non glare acrylic 17"x22	Clear		Tap Plastics	$15.32	$15.32
7	1	1/8" ABS sheet 18"x24"	Black		Tap Plastics	$15.32	$15.32
8	1	Miscellaneous SS fasteners				$12.45	$12.45
9	1	Pelican waterproof case		1600	B&H photot and vid	$129.99	$129.99
10	1	*Water jetted pieces of alluminum*			*Janicki Industries*	$150.00	$150.00
							$658.12
Gripper and mission sled							
1	1	Flat I-line 1.5"x1" air actuato	#F0-171-GS		Bimba	$69.35	$69.35
2	1	Miscellaneous SS fasteners			Ace Hardware	$35.00	$35.00
3	1	Metric tape measure	#T20001		Grizzly Imports	$7.25	$7.25
4	1	LED pond light	#LDS10W		Lowes	$32.99	$32.99
5	1	*Water jetted pieces of alluminum*			*Janicki Industries*	$400.00	$400.00
							$544.59
7							Total cost:
							$1,862.11

Appendix B: Motor Controller Schematic



Fuse = 

Appendix C: CAD Model of the Omega Machine



Appendix E: Pneumatic Diagram