LONG BEACH CITY COLLEGE
Long Beach, California
EXPLORER CLASS

Viking Exploration and Recovery Co. (VER)

ROV: The *Viking* *HAMMER*

*H*igh-tech *A*quatic *M*achine *for* *M*apping *E*xploration *and* *R*ecovery

Technical Report

11th Annual MATE International ROV Competition

TEAM

Yasin	Khalil	Assembly, Design, Software, Electronics, Pilot, “CEO”
Stephen	Estrin	Machining, Design, Assembly, Co-Pilot, “CFO”
Joshua	Reyes	Assembly, Wiring, Testing, Pilot, “CIO”
Tara	Willis	Assembly, Testing, Tether Manager, “Ops Director”
Mike	Marin	Assembly, Testing, Documentation, “CAD Director”
William	Courduff	Testing, Wiring, Assembly, “Production Coordinator”
Eric	Frantz	Design, Fabrication, “Design Director”
Heidi	Park	Fabrication, “Project Manager”
John	Millar	Documentation, Fabrication, “Corp. Secretary”
Scott	Fraser	Instructor, Board of Director

ABSTRACT

The Viking *Hammer* was conceptualized and constructed by the Viking Exploration and Recovery Co. (VER), specifically for the exploration of a shipwreck, and the removal of hazardous materials contained within. There are four vertical thrusters, welded 20mm^2 aluminum framing extrusions, and custom designed sampling tool used to process the wrecks hazardous materials without posing any risk to the surrounding environment.

Utilizing the computer software SolidWorks, the *Hammer* was designed in a virtual three dimensional environment, and its components were cut with a 3-axis CNC mill. The *Hammer* is the result of a year's worth of technical discussions, software meetings, and operation functionality debates. Combining the time and talent of each team member, the *Hammer* was created to efficiently complete the tasks of surveying the wreck site, and removing the fuel oil from the wreck itself, as well completing all the sub-tasks requested by employing the use of a custom gripper, cameras, measuring device, and hazardous material removal system.

The *Hammer* was designed to exhibit superior, controlled vertical movement and maximum water flow; both of which are necessary to complete the mission tasks in an efficient and reliable manner. Measuring 29.2cm in height, 34.3cm in width, 53.3cm in length, and weighing 16.63kg, the *Hammer* embodies countless hours of hard work, exceptional engineering skills, and working knowledge of state-of-the-art fabrication methods. Through careful design and utilizing custom tools, the *Hammer* and the Viking Exploration and Recovery Co. are able to provide effective and efficient means of operational excellence within the marine environment.

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FINANCIAL REPORT

2012 Viking Exploration and Recovery ROV Financial Report

	Part	Quantity	Reused Value	Donated Value	Cost
1	Buy: 40A Circuit Breaker	1			$ 12.76
2	Buy: 8020 Aluminum Extrusion	1			$ 176.35
3	Buy: Air line connectors	4			$ 7.56
4	Buy: Circuit Boards	6			$ 198.00
5	Buy: Electronic Components	misc			$ 384.28
6	Buy: IP68 Cable Glands	18			$ 42.84
7	Buy: Misc Hardware	1			$ 76.25
8	Buy: NEMA Twist lock connectors	1			$ 4.75
9	Buy: O-Rings	10			$ 7.62
10	Buy: Stainless steel hardware	misc			$ 35.27
11	Discount Buy: Seabotix Thrusters	2		$ 510.00	$ 1,296.84
12	Discount Buy: Teledyne Connectors	2		$ 174.50	$ 189.76
13	Donation: Boeing Aluminum stock	30 lbs		$ 275.00	
14	Donation: CSULB 4' x 8' High Density Foam	1 sheet		$ 547.76	
15	Donation: LubeCo Metal Anodizing Services	1		$ 500.00	
16	Donation: SMP - Metal Welding Services	1		$ 500.00	
17	Donation: SubSalve USA Lift Bag	1		$ 50.00	
18	Donation: VideoRay Tether	25m		$ 450.00	
19	Donation: Weeks: 2.5" x 12" PVC Rod	12"		$ 13.26	
20	Reused: 1/4" standard male air connector	1	$ 1.89		
21	Reused: Air Regulator	1	$ 150.00		
22	Reused: Camera boards	4	$ 180.92		
23	Reused: Joystick controller	1	$ 7.27		
24	Reused: LCD Monitors	2	$ 300.00		
25	Reused: Left over acrylic tubes from 2009	1	$ 105.95		
26	Reused: Misc Cables	misc	$ 47.56		
27	Reused: Pneumatic Tubing	200ft	$ 34.00		
28	Reused: Pneumaticy Cylinder	1	$ 48.34		
29	Reused: Thruster motors	4	$ 3,400.00		
30	Reused: Tool box for Control housing	1	$ 47.00		
31	Reused:Air Manifold	1	$ 375.00		
			$ 4,697.93	$ 3,020.52	$ 2,432.28

Fundraising	$ 4,530.00
LBCC Electrical Dept Funds	$ 693.08
Total Budget	$ 5,223.08
Amount Spent	$ 2,432.28
Balance	$ 2,790.80

SURFACE ELECTRICAL SCHEMATIC

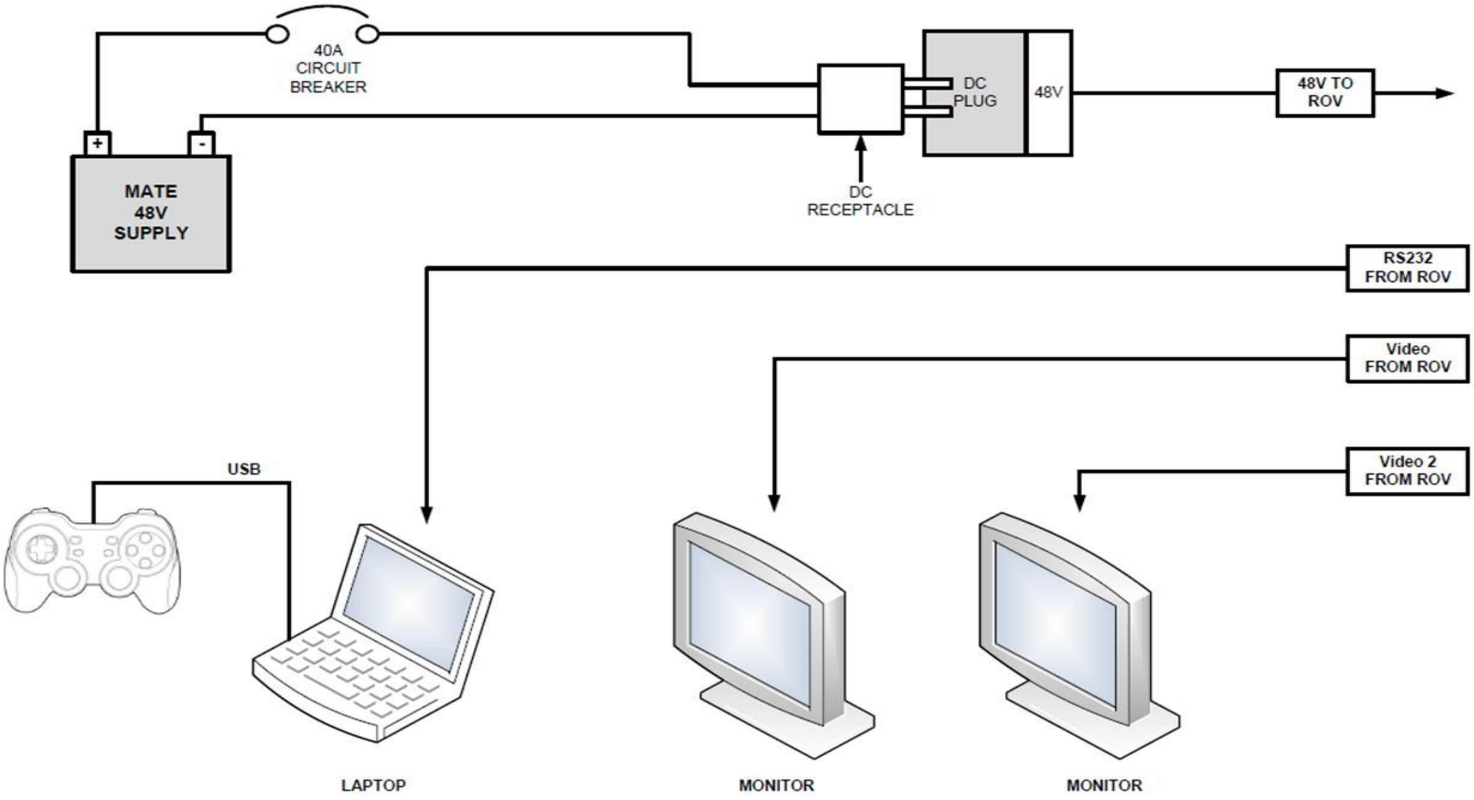

FIGURE 1 SURFACE ELECTRONIC SCHEMATIC

ROV ELECTRICAL SCHEMATIC

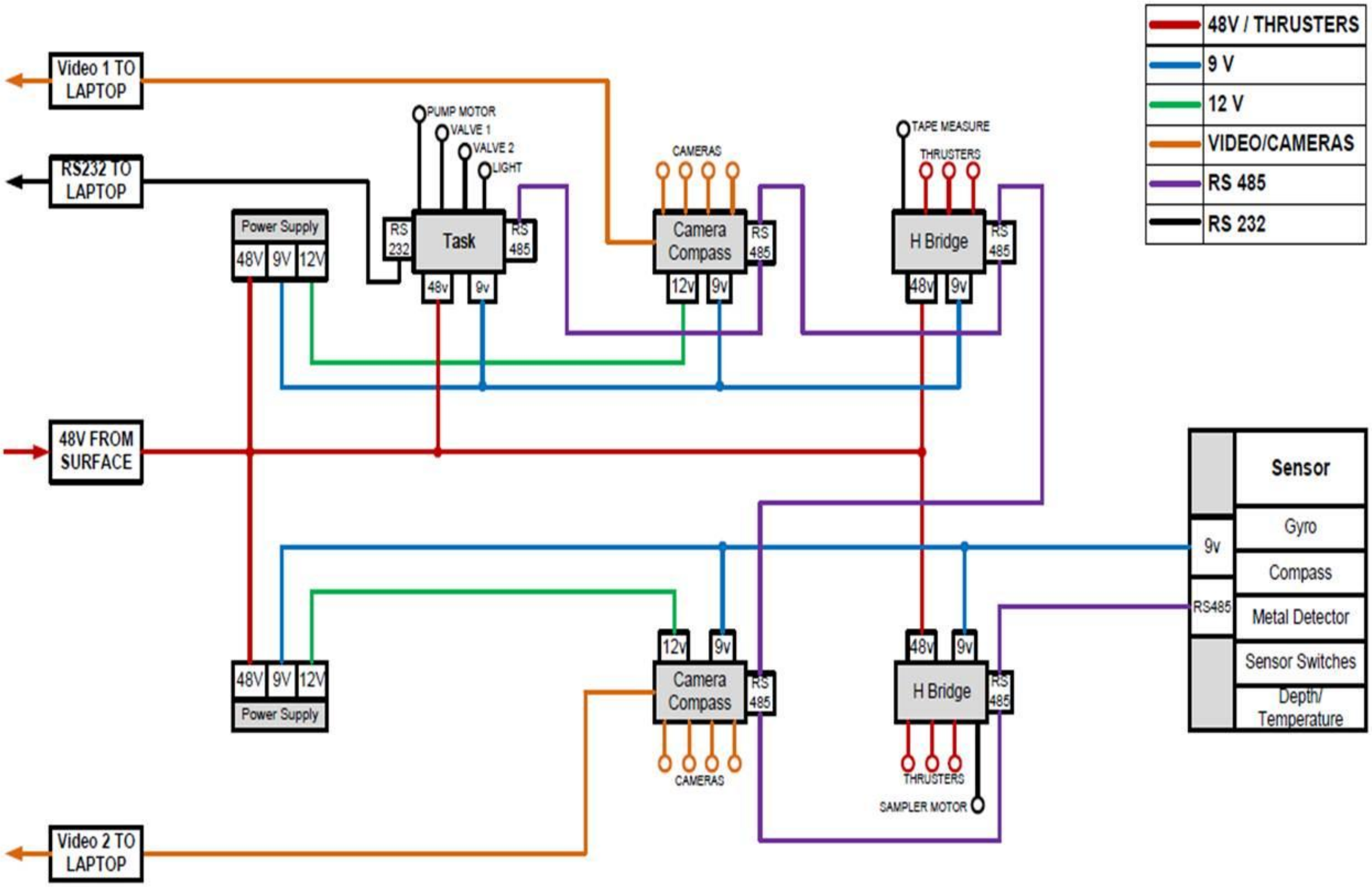

FIGURE 2 - ROV ELECTRONICS SCHEMATIC

DESIGN RATIONALE - TASKS

As more shipwrecks are beginning to deteriorate, the assessment and removal of hazardous material is becoming an urgent issue. While designing the devices to carry out our required missions, we continually kept the practical applications in mind. Each of our task specific components are engineered to withstand conditions and application far beyond what will actually be required. This will be evident as we explain in detail the *Hammers'* technical capabilities.

TASK #1 - SURVEY THE WRECK SITE

Measure length of ship

The members of Viking Exploration and Recovery Co. designed two devices to measure the length of the ship. One was a more technical approach involving an optical sensor that relayed the number of rotations made by a spool while traversing over the ship which was integrated into a predetermined formula. While the other design took a simpler approach involving a spool of pre-marked string that would be attached to one end of the ship and pulled the length of the ship. Both methods were prototyped, and, due to some unforeseen challenges with the sensor relay and the success and accuracy of the spool and string, the more rudimentary spool method was implemented.

Determine orientation of ship on sea floor

It was unanimously decided by the VER team that in order to determine the orientation of the ship on the sea floor an on-board sensor would be used. By utilized the cameras and this compass sensor, the orientation of the wreck site will be determined by piloting the *Hammer* along side or above the ship and a reading will be taken from the compass sensor. Using this reading and comparing it to a North reading the layout of the site will be determined.

Examine debris field alongside the wreck

To examine the debris field alongside the wreck and determine whether or not the objects were metal, we designed, prototyped, then created our own metal detector circuit and sensor. We designed the circuit using a bread board which read the inductance of a copper coil; this sensor is used to measure the debris field alongside the ship. When the coil comes into close proximity with metal, the inductance changes thereby revealing a metal object, and we are able to detect this change in our circuit. Also, in an effort to add redundancy to the *Hammer*, the position of the compass was moved to the bottom of the ROV as a compass needle will deviate from due north when swept over metal producing a make-shift metal detector.

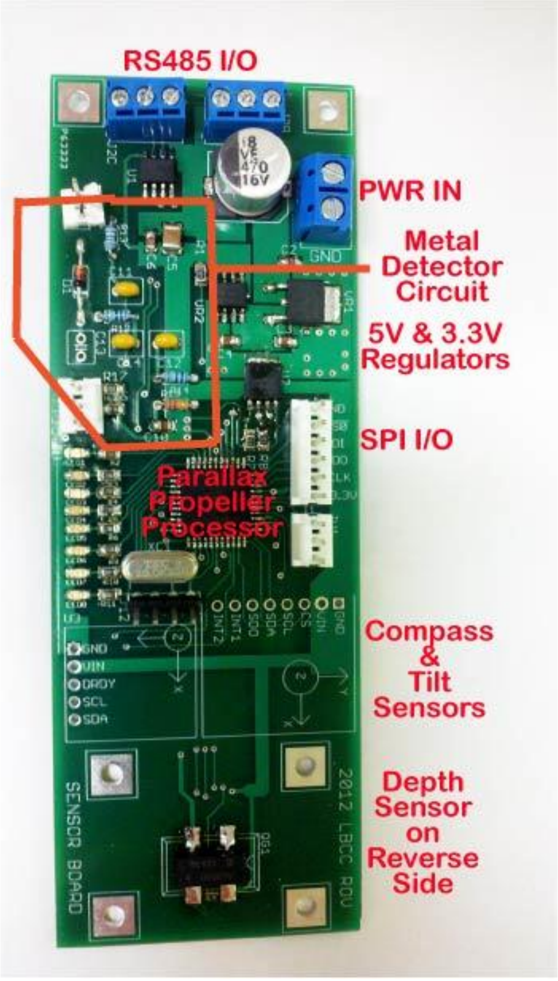

FIGURE 3 - SENSOR BOARD

Make map based on findings

It was decided that a member of the company would be on hand to draw all the information gathered by the live video feed from the *Hammer*. This will supply the team with enough information to accurately map the orientation of the ship as it appears on the ocean floor.

Simulate scanning with sonar (minimal overlap)

Simulating scanning with sonar requires our pilot to place the ROV in line of sight with a set of stationary cavities. These cavities have patterns on their backgrounds, and, in order to complete this task, the *Hammer* must transmit a clear and complete video shot of these patterns back to the surface. The *Hammer's* ability to move horizontally about the water column, independent of vertical motion due to the vector thrusting, allows for an optimal plane of travel. The *Hammers'* vector thrusting affords a minimal amount of maneuvering from one sonar location to the next.

TASK# 2 - REMOVING FUEL OIL FROM THE SHIP WRECK

Transporting and attaching lift bag to the fallen mast

Moving the fallen mast requires the *Hammer* to first transport and attach a lift bag to the wrecks mast, which will then be inflated using a pneumatic line connected in tandem with the gripper. The critical design feature of this task component was determining the coupling method for the inflation line. After much debate, the team ultimately decided upon a coupling process utilizing two tubes, one with an inside diameter the size of the others outside diameter. This allowed for a dependable airtight seal that could be released with minimal effort. This design allows the *Hammer* to place and deploy the airbag accurately, with confidence in the seal, then remove the mast from the wreck site.

Removing coral from ship's hull/Transporting the coral

In order to remove the coral from the ship's hull and transport the coral to a predetermined area, the *Hammer* was equipped with a pneumatically actuated gripper. The grippers secure design enables it to grip and hold a wide range of items necessary for specific tasks for exploration and recovery. The *Hammer's* custom design gives it the manuvering capabilities to extract and relocate coral from the wreck to a precise location.

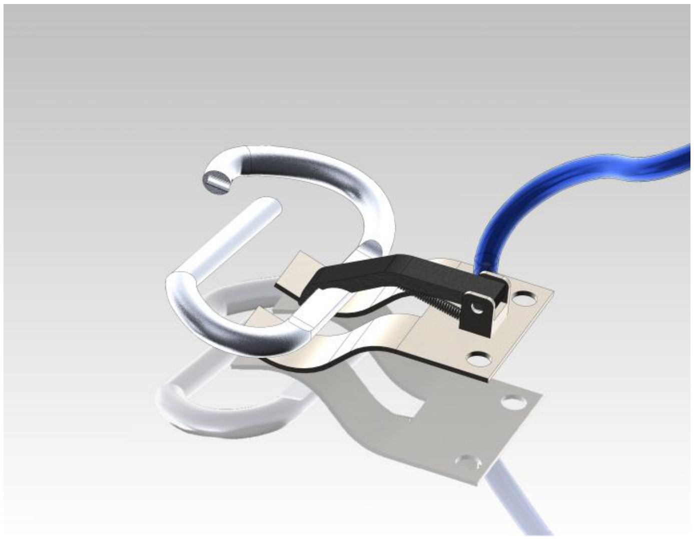

FIGURE 4 - LIFT BAG DEPLOYER

Simulate drilling/Remove oil /Reseal hole

The final task is comprised of an all in one task component that was designed to complete all the fuel tank related tasks in a single docking. More time overall was delegated to the design and fabrication of this specialized component than any other. We foresaw the ability to dock this tool to the fuel tank with precision as vital to the success of the task. A tiered system of guides was chosen to aid in the initial docking. By providing tiered voids, the tool will dock to the drill site with ease, stability, and security.

Next we incorporated a custom dual pronged hollow “drills” to penetrate the petroleum plugs. In the same action of penetrating the petroleum, the tool will seal the drill sites behind the drill bits. The drill bits are hollow and are connected two on board pumps. Once sealed the drill bits and fuel tank create a pressure loop, the pump connected to a predetermined drill bit will push clean water into the fuel tank, at the same time forcing the oil out into the other hollow drill bit. After the oil is pushed through the bit it will travel to a sample reservoir.

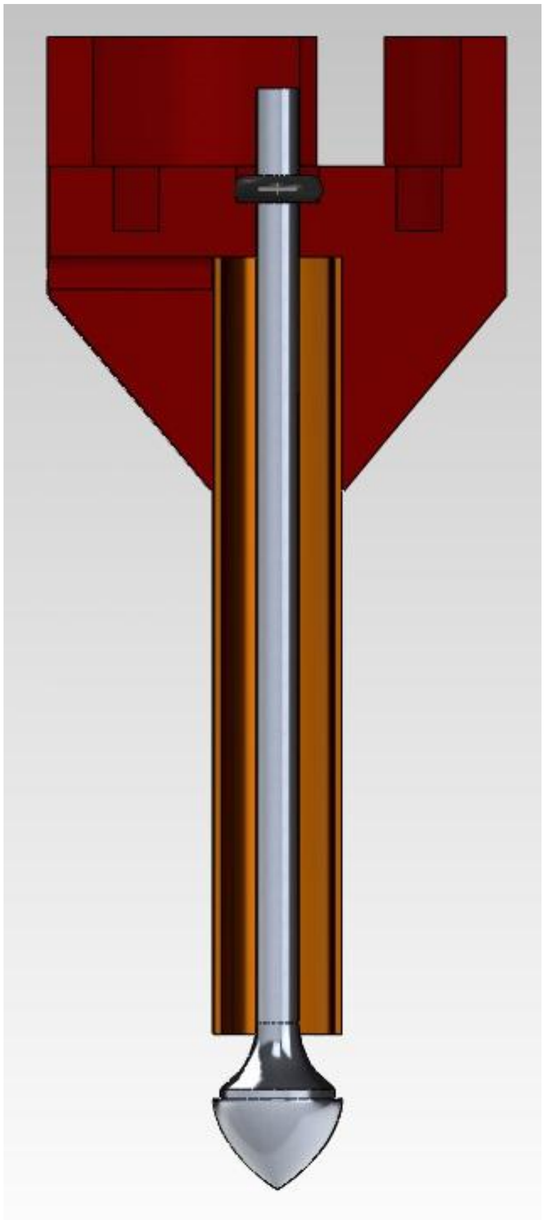

FIGURE 4A - FUEL DRILL

DESIGN RATIONALE – ROV COMPONENTS

In the beginning stages, the team found it difficult to accurately communicate complex technical design ideas while in their infancy between members. This complication was at times counterproductive. Designing the *Hammer* in three dimensions allowed each member to present and receive true to form representations of individual design ideas. Typically the task design discussion was ongoing, allowing for individual brainstorming. Once the team agreed upon a final design idea, a member was charged with completing a virtual scale model in three dimensions. After the model was created, the file was programed into our in house 3 axis CNC mill, and the part was cut from the raw materials. These skills afforded the team the freedom to fabricate almost any piece necessary to complete a working system.

ROV FRAME

Of the components, the frame was one that we had spent the most deliberation on. Since each sub-system is mounted upon it, the frame must be versatile enough to withstand future modifications to components, while maintaining functionality. The primary features of the frame are: its modular design, improved water flow, vectored vertical thrust, and maximum stability and strength.

The material used to construct the frame is extruded aluminum. These 20mm by 20mm bars are incredibly strong, yet light weight. The bars themselves weigh only 0.4732 kilograms per meter. However the main feature of the aluminum extrusions is the T-slots. They allow us to place a bolt anywhere on the frame. This gives us the ability to easily adjust, relocate, or replace any component. By utilizing these bars we were able to reduce any major obstructions to water flow.

To ensure the safety of our components our frame would need to contain a durable design. However we also needed to reduce weight and bulk. We chose a trapezoidal shape to provide the maximum amount of structure for the amount of material used. We placed the angle of the support bars on the trapezoid at 60 degrees. This provided the optimal angle for our vectored thrusters to be mounted. At 60 degrees we still have the majority of our thrust optimized for vertical movement; however we are still able to reverse one side of our thrusters to create lateral motion. Enabling the pilot to perform crabbing movement increases the ROVs maneuverability when docking our payload to the tasks. Overall the modular design, vectored placement of the vertical thrusters, and incredible structural integrity the aluminum frame provides combines together to ensure the *Hammer* is versatile, efficient, and reliable. Its applications go beyond those requested of it, ensuring it stays useful for years to come.

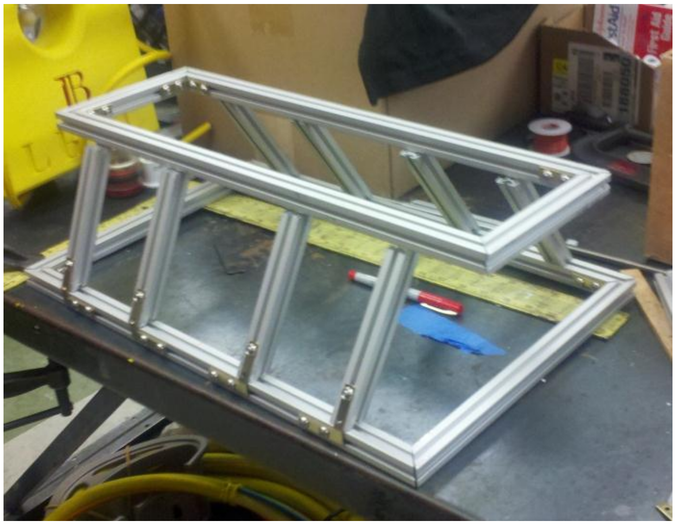

FIGURE 5 - UNWELDED ROV FRAME

ELECTRONICS HOUSINGS

The *Hammer* has two electronics housings on the port and starboard sides. Each electronics housing is comprised of a front and a rear section. The housing is made of acrylic tubing's, with two aluminum end caps, and an aluminum center cap that fuses the two acrylic tubes together. All of the *Hammers*' circuits are carried on an aluminum tray which not only holds the electronics, but also acts as a grounding plate and a heat sink. The tray is welded to the center cap to hold it in place, as well as expose the heat of the system to the surrounding. Each center cap has water proof connectors that are used for plugging in various thrusters and payloads that are needed. The *Hammer* is equipped with two H-bridges, a task control board, two power supplies, and a video control board.

ELECTRONICS

1) H-BRIDGE

The *Hammers*' H-Bridges were designed to be four channeled; in that each board can control up to four motors in both forward and reverse directions. The Board is powered by +48V from the tether for the thrusters and takes in +9V from the power supply for operation.

2) Task Control Board

The Task Control board was designed to receive strings of data from the surface that tell the board which task payloads the *Hammer* needs to operate. The task control board has many sensors which include an accelerometer, a magnetometer (compass), a temperature sensor, and a depth sensor.

3) Power Supply Board

The power supply board is the main power distribution board. There are two of them, one in each electronics housing. The board is supplied with +48V, and regulates the voltage down to +12V and +9V.

4) Video Control Board

The video control board is exactly that. It is the interface for all of the various cameras on *Hammer*. Each camera plugs in and then is relayed back to the surface through a coaxial cable inside of the tether.

All of the Caps (Center, and End's), circuit boards, the housing's, and the mounting plates were designed and fabricated by the Long Beach City College ROV Team.

FIGURE 6 - SEALED ELECTRONICS HOUSING

THRUSTERS

The propulsion system on the *Hammer* was designed in such a way to obtain a high level of control and maneuverability. There are a total of six thrusters mounted directly to the *Hammers'* frame. Two of which control horizontal movement, and four control vertical and lateral motion. The four vertical thrusters are each mounted at a sixty degree angles facing inward. This slightly reduces the thrust when moving vertically, however it enables us to reverse the direction of two of our thrusters and obtain a lateral motion. There were multiple thruster configurations designed; staggered thruster on the interior of the frame allowed us to reduce the width of the ROV, thruster on the exterior of the frame added bulk and vulnerability of the components but reduced the chance of twisting when operating. To resolve these conflicting designs and determine the most effective configuration we built multiple prototypes of the frame made in PVC. This enabled us to mount our thrusters in a certain configuration on the prototype then perform underwater test in front of a grid which was recorded then analyzed. The result of our tests is the *Hammer*, with its interior staggered vertical thrusters it was the most effective design.

TETHER

The tether is the *Hammer's* umbilical cord to the surface and command controls. Within a protective sheath are four power cables to transfer the needed 48 volts to power the communications, pneumatic, and video lines. The power for the 21.5 meter tether was wired in parallel to help limit voltage drop across the length of the tether. Two lines are run through twisted pairs for the serial communications signals. Video lines are run through coax for the video feed from our two camera boards. The *Hammer* can be modified to accommodate and support a total of eight cameras through these lines. There are two lines to run the pneumatics that control the grippers necessary for the tasks of this mission. Plastic tubing was used to provide the tether with neutral buoyancy as to not hinder the operation of the *Hammer* in the water. The tethers is managed by a mounting system on top of the ROV to provide an effective and efficient way to store, transfer, and deploy the tether on site.

FIGURE 7 - VERTICAL VECTORED THRUSTERS

CAMERAS

It is important that the ROV pilot be provided with good visual data to base decisions upon. This is why good clarity and multiple views of the environment are crucial on an ROV. Along with redundancy, this was the driving concept behind our camera design. We decided that a modular and compact camera design would be the best approach. After the team had designed the relatively simple cameras, the matter of their layout led to the development of some very interesting techniques.

Inside the computer design program SolidWorks, the team discovered a function that allowed the simulation of camera views. With this function, the team was able to modify the simulation to account for the distortion of the camera view caused by being in water. Once this was complete, we were able to shift the locations of the cameras on the vehicle to create highly functional views of all the payload equipment for the ROV's pilot.

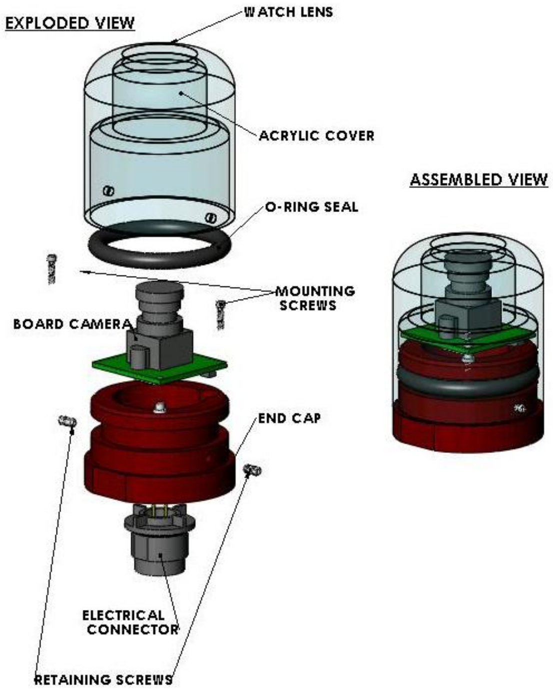

FIGURE 8 - SOLIDWORKS EXPLODED VIEW OF CAMERA

The placements of our cameras for the primary operational view are in such a way to provide stereoscopic vision to our pilots. Since we utilize multiple monitors and dual video boards we placed multiple cameras facing the bow enabling depth perception. These features along with the task specific views will enable our pilots to obtain the information they need to effectively pilot the *Hammer*.

SAFETY

Due to the potential hazards when working with vehicles such as the H*ammer* we included certain safety features in the design. Since the chemicals in the water conduct electricity we sealed all of our connections as well as our electronics. In the event of a short circuit we have also included a 40 amp circuit breaker. To prevent damage to the electrical system which could result in a short circuit condition, we installed a strain relief on the ROV as well as developing tether management system when the ROV is in transit. As far as hardware safety features are concerned by removing any sharp edges from the frame and chamfering the corners, this ensures that those assembling and repairing the ROV are protected including any item in the surrounding environment, such as divers. The thruster propellers are housed within a plastic shroud to protect those handling the ROV and aquatic wildlife. These features protect the divers, the operators, and those near the machine during operation.

CHALLENGES

Although we faced all the typical challenges associated with designing and constructing an advanced robotic system from scratch, coordinating the schedules of the entire team, proved to be the most difficult non-technical challenge the Viking *Hammer* team faced. In addition to being active participants in the ROV Club, the majority of the team members were also enrolled as fulltime students at LBCC. In addition, most team members had employment outside the walls of academia. Throughout the work week, each team member was expected to work diligently on their contributions to the *Hammer*, and on keeping all members updated on individual progress. In the interest of progress members were expected to meet together weekly. E-communication played a vital role in the *Hammer* building process, as ideas were constantly streamed back and forth between team members. Without a diligent effort from each member to be present each week, as well as to make progress on the *Hammer* during their personal free time, the *Hammer* would not have been operational in time.

During the process of welding our electronics mounting plate to our center cap, over exposure to heat melted a hole in the joint, compromising the integrity of O-ring groove. This complication rendered the seal permeable, negating the sealing properties of the center cap. A leaking seal lends itself to electronic failure, and inevitable loss of system functionality and control. It was decided that the interior O-ring groove wall would be milled down to allow for a sealing material to fill the breach and reestablish a reliable seal. The electronics housing tube was then permanently attached and sealed with a silicone caulking. While not optimal, this solution allowed for access to the circuit boards and was watertight

TROUBLESHOOTING TECHNIQUES

An essential aspect of the building process is the troubleshooting. Although every system is designed to work properly the first time, there are always issues that arise. One such issue was the electrical system, we found after applying initial power that the voltage would drop dramatically; this was due to a short circuit within our system. Our current limiting power supplies prevented any damage however we still needed to locate the source of the issue. This was done by the use of an ohm meter. We isolated sections of the circuit then measured the resistance. The team determined that the location of the short was within our circuit boards. After careful examination we realized that the standoffs separating our circuit boards from the heat sink plate were not long enough to prevent the through hole components from contacting the aluminum plate. To combat this we increased the length of the standoffs. Once the short circuit was repaired we were able to rewire the electronics and the boards worked as designed.

Another aspect of troubleshooting that the team came across was programming the *Hammers'* electronics. There were multiple issues in relation from the software to the hardware. One such issue was the H-Bridge code. When programming the H-Bridges, due to faulty soldering, we had difficulty with its communication. The team found that using a debugger to read the serial data going out helped to determine such faults within the electronics. We then repaired the soldering error, resolving any electronics issue we had.

Creating a sealed system for the newly repaired electronics became a difficult task. Visual inspection was not sufficient in determining that the housings were sealed, we applied multiple troubleshooting techniques to ensure a water tight system. Once the housings were presumed sealed we would pull a vacuum using a hand pump. This simulates a positive pressure on the outside of the tubes that would be generated at depth, without the possibility of water damage if the housing was not sealed. Once the vacuum was pulled, we recorded the amount of negative pressure applied to the tube. After a period of time if the pressure decreased then we knew that theoretically water would leak into the enclosure. After determining that the housing was not properly sealed we had to determine where the leak was coming from. This was done by reversing the hand pump and creating a very slight positive pressure in the housing. To ensure the safety of this procedure we all wore personal protective equipment as well as placing a shield around the enclosure.

When it was determined the seals were in place, tests were run on terra firma making sure all of our components were properly working. Once the systems check was complete, sea trials were set to begin. We placed the *Hammer* in an outside water tank to check the ballast. By carefully adding and positioning weights we determined neutral buoyancy, and were then set to place the *Hammer* in the pool for further testing. The control equipment was transported and established next to the pool and the *Hammer* was placed in the water. The pilot systematically went through and tested the functionality of each of the thrusters. By going through each combination of vector controlled movement, it was determined through these thorough tests that one of the thrusters' polarity was reversed. This was a quickly remedied back in the lab.

FIGURE 9 - TARA, YASIN, AND MIKE TROUBLESHOOTING THE ELECTRONICS HOUSINGS

FUTURE IMPROVEMENTS

As we contemplate the design of our finished product a few decisions stand out as those which could have been done more effectively. Although we are satisfied with the design, not every aspect reached its full potential. One Improvement we will make in the future is the layout of our PCB circuit boards. In the design of our circuit boards using Eagle CAD we placed components within close proximity of each other, in an attempt to save space within our electronics housing. This caused multiple issues when soldering the components, since we used a new method of soldering which utilized a toaster oven and the melting and soldering of every component simultaneously. Although prior to use each board was visually inspected then tested, we still encountered damage and soldering errors within our boards. To prevent issues such as these in the future we will, when designing the circuit boards, allow for additional space between components on our circuit boards, as well as return to the manual soldering method.

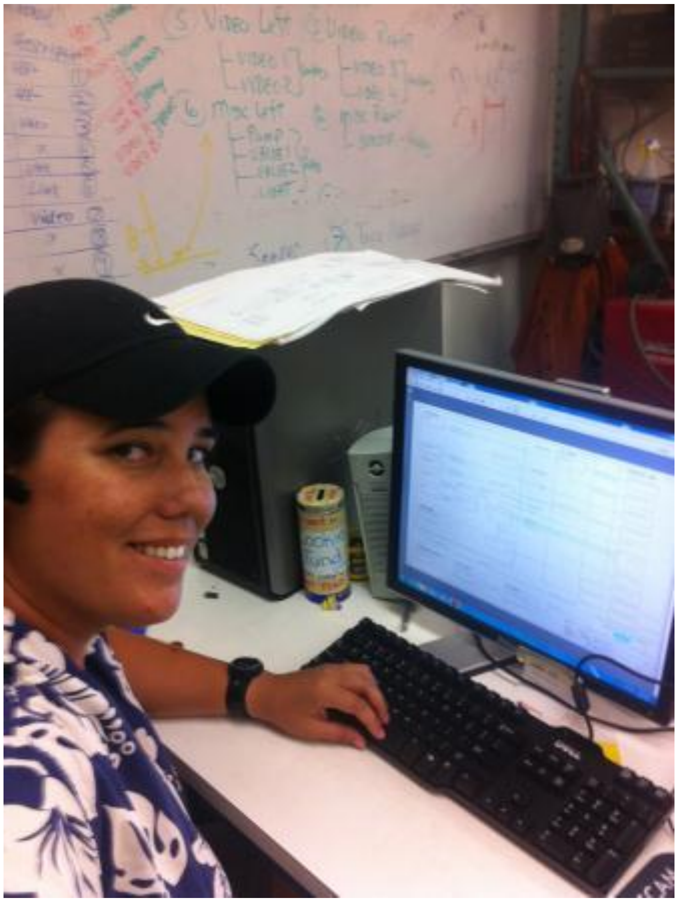

FIGURE 10 – TARA WORKING ON DESIGN

LESSONS LEARNED

Given the capabilities of the *Hammer*, Viking exploration and recovery had to design and fabricate a number of custom circuit boards. The *Hammers'* circuit boards utilized numerous surface mount components. Due to their minuscule size, the surface mount components require a skill level beyond the casual solder to mount correctly. With the number of surface mount components needed to be mounted, the team searched for the most time effective method to get all the components mounted. The method decided on, was one that involved placing the components on their place on the board, apply liquid solder to their terminals, and baking the board to finalize the connections. At first glance this method seemed to work with little error, in fact after the first board was completed in this manner, the boards were being produced at 1/10th the rate it would have taken to solder the components one by one by hand. After the boards were completed, a small number failed there functionality tests. Most boards however passed their tests and were installed on the *Hammer*. As an assembled system, despite testing fine prior to installation, a few boards had flaws and quirks. After inspection with a magnified view, it was apparent the method used was time effective, but far from perfect. The flawed boards often had solder bridges and outright bad connections on key components. These errors were discovered and corrected to get the boards to total working condition, but time was lost troubleshooting them. In retrospect it is clear that the method used can in fact save time and effort, but still requires practice and care. The time it took to trouble shoot and correct the errors, was most likely close to being equal to the time saved if the boards surface mount components had been done one by one, by hand in the classic fashion.

On a personal level, the team realized no idea is a bad idea. During the early stages of the design process, a team member mentioned they had a great idea for the oil sampling apparatus, but failed to iterate the details or even basic concept of the design in fear it would be seen as a bad idea. The discussion moved forward, and another members design was agreed upon to fabricate. As time went on, the member who failed to speak up silently worked on designing their apparatus. The design agreed upon for the oil sampling, was tested and unfortunately failed. Much time was spent on its design and troubleshooting. After the team had decided to find a new design, this silent member came forward with their original design, in a three dimensional format. It was well received, and fabricated and worked after minor tweaks. Going forward the team realized no idea was a bad idea.

FIGURE 11 - BILLY WORKING WITH HOUSING AFTER TESTING FOR LEAKS

REFLECTIONS ON THE EXPIERENCE

As our team, Viking Exploration and Recovery, embarked on this year's competition we were faced with many challenges and successes. From the very beginning, the *Hammer's* design was in constant debate amongst teammates. And through differential design diagnosis and brainstorming, the design was conceptualized with the allowance of maximum water flow and maneuverability in mind. Its open framework design illustrates the many hours of debate and the execution of fabrication was a collaboration and a collective team effort. As individuals, we each showcased our skills in the creation of a final product logging countless hours getting the *Hammer* complete. By working as a close team, as challenges arose, they were quickly troubleshot and fixed, making repairs like a surgical team passing necessary tools across the room to get the task done. We quickly logged a number of successes lifting the morale of the team as each challenge was faced and conquered. Our largest success was seeing the *Hammer* in the water for the first time and not watching it sink to the bottom of the pool. It was at that point, when we knew it was working, that all of our effort as a team and personal sacrifice had paid off and the *Hammer* was ready to execute the tasks it was so carefully designed to do. From each challenge that was overcome, each team member gained skills in working in a team environment as well as in a high stress technical field. Individual ideas were debated and executed by the team. We were able to showcase individual skills and knowledge, but the collaborative environment that was encouraged gave us skill that we will surely utilize in "real world" application.

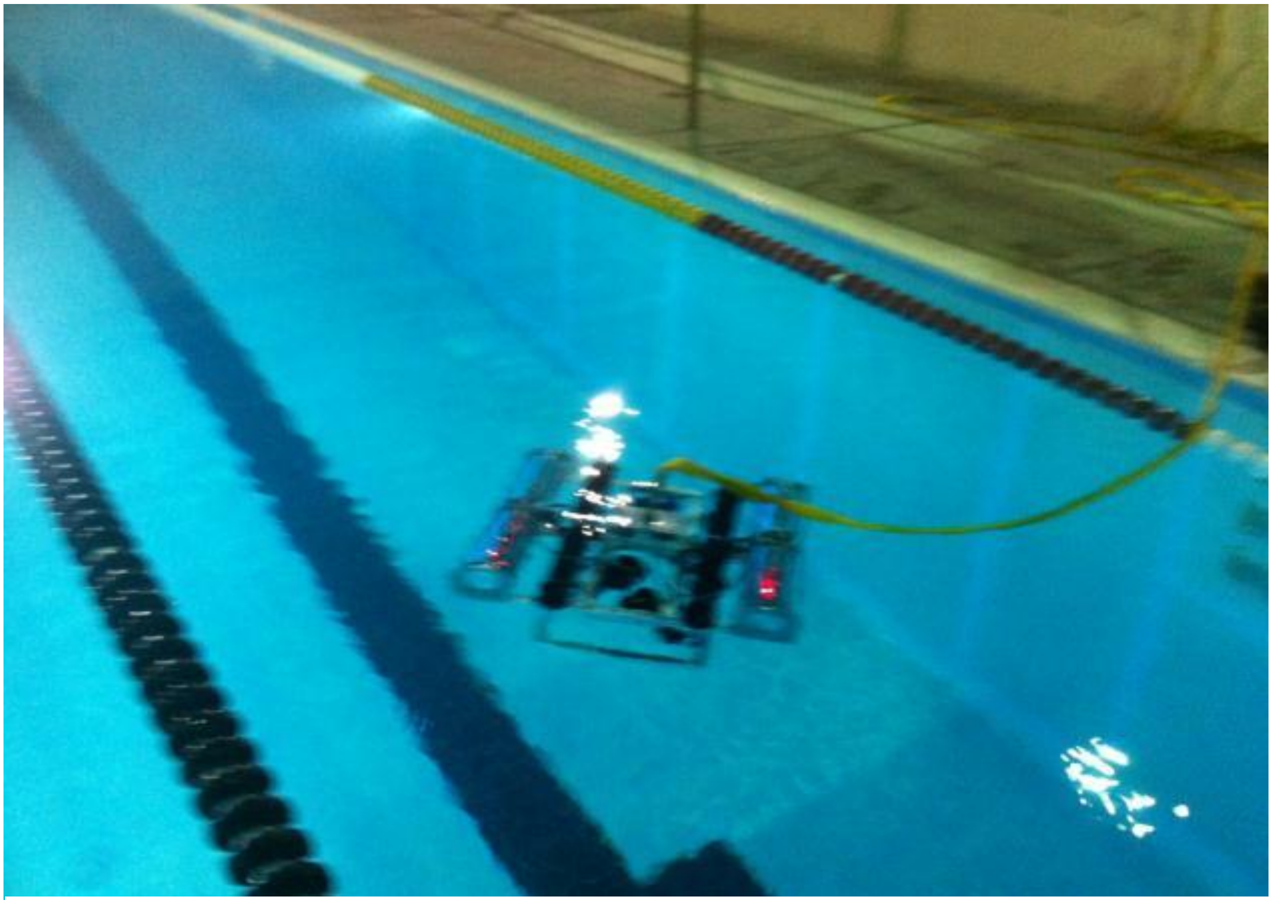

FIGURE 12 - HAMMER FULLY OPERATIONAL

SOFTWARE FLOWCHART

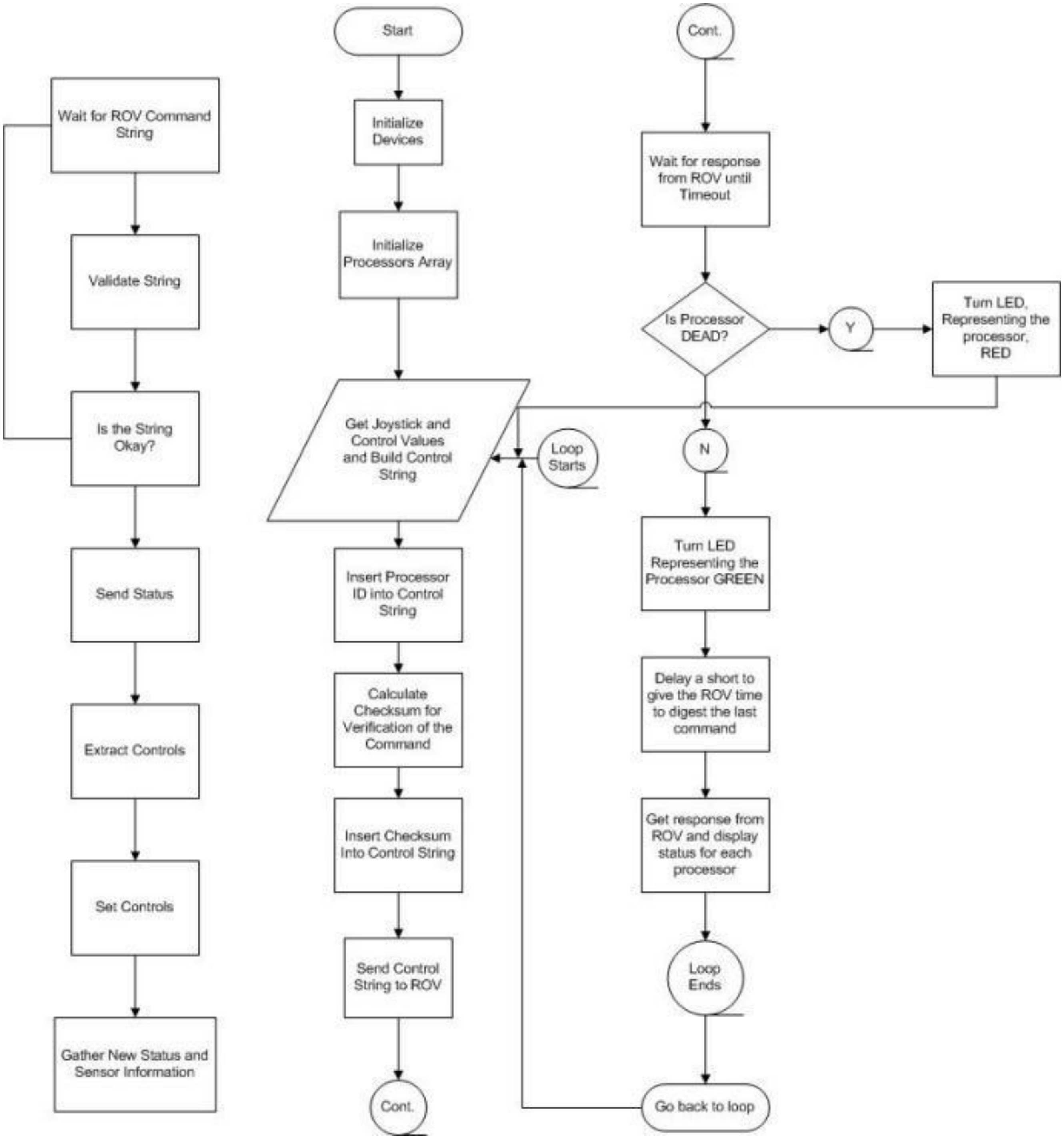

FIGURE 13 - SOFTWARE FLOWCHART

TEAMWORK

If not for the collective efforts of the individual Viking Exploration and Recovery team members, the *Hammer* would not have come to be the High-Tech exploration and Recovery vehicle it is today. There were times during construction that every team member was working as one, on the same troubleshooting task. When the time to create the technical report arose, each and every member supplied information and creative input regarding any process they had been a part of. Not one person was solely responsible for any aspect of the *Hammers'* design or creation. To increase efficiency, Viking Exploration and Recovery separated into sub-teams. Each group worked together to design, fabricate, troubleshoot, and test an individual sub-system or component. Periodically the entire company would meet to report status, make decision, and determine the proper direction to continue. To ensure that we would have productive meetings with progress to report we appointed a Project Manager. The Project Manager assigned task, set deadlines, and scheduled meetings and events in addition to the primary ROV tasks. The teamwork displayed amongst the company directly contributed to the success of *Hammer*.

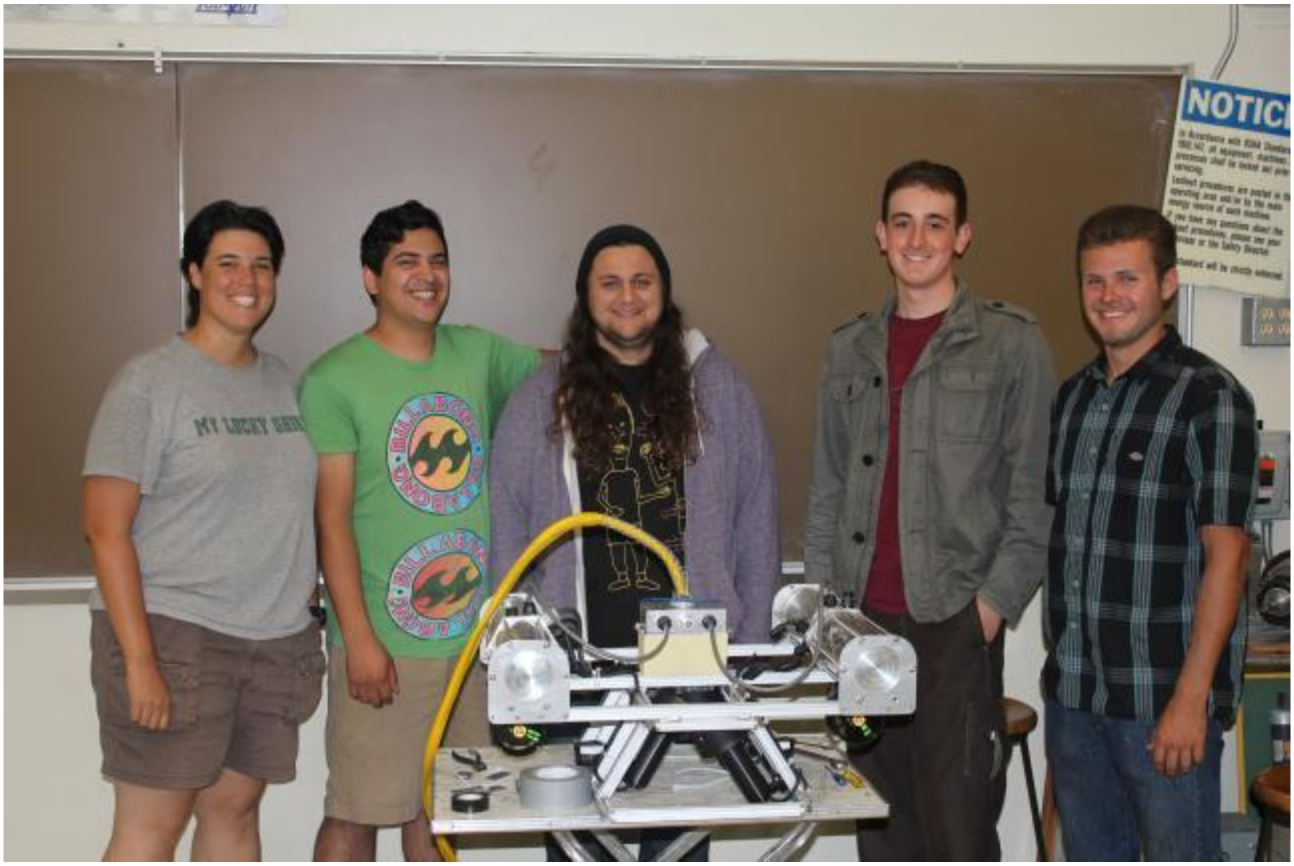

FIGURE 14 - VER PHOTO FROM LEFT TO RIGHT; TARA, JOSH, YASIN, STEPHEN, WILLIAM.

ACKNOWLEDGEMENTS

THANK YOU TO ALL OF OUR SPONSORS AND THOSE WHO HELPED MAKE THE ROV HAMMER POSSIBLE.

WE APPRECIATE YOUR PARTICIPATION!

Boeing
CSULB
LBCC Electrical Department
LubeCo,
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Seabotix,
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Teledyne
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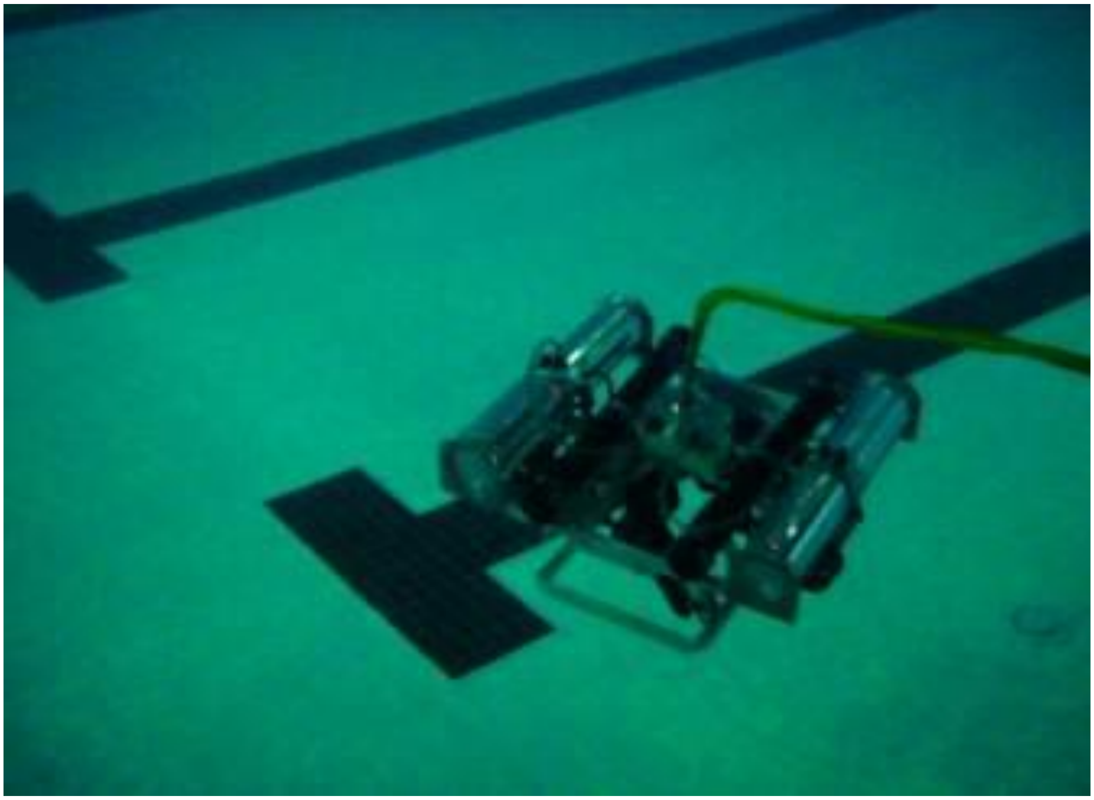

FIGURE 15 - COMPLETE INTACT PHOTO OF HAMMER