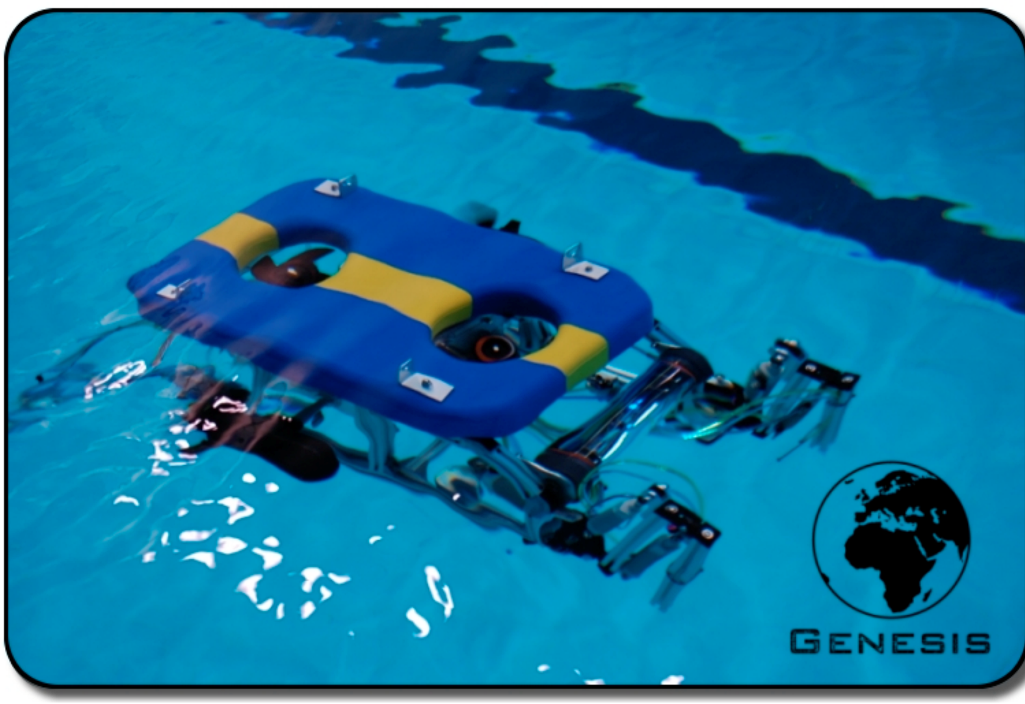
Sea-Tech 4-H
Skagit Exploration And Marine Technology 4-H Club

Skagit County 4-H Program – Washington State University Cooperative Extension Office

TEAM GENESIS



Team Members
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Keegan McAdams and Peyton Hasenohrl

Team Instructor: Lee McNeil

Abstract

The Genesis ROV is Sea-Tech 4-H Club's entry into the 2008 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 basic design uses a universal frame to mount pressure resistant mission packages, thrusters, cameras and a foam float assembly to achieve the desired ROV configuration. Four customized 12 volt trolling motors provide vertical and lateral thrust. A pneumatic power system operates two manipulator arm assemblies, with interchangeable grippers, that are used to manipulate or retrieve objects from under the water. The camera assembly tilts through 360 degrees of rotation to allow for a greater range of vision. The hydrostatic-proof polyurethane foam float provides slightly positive buoyancy. Sliding zinc-alloy weights trim the ROV for attitude. These weights can be modified for variation in displacement as mission packages are changed.

The ROV systems were designed and assembled by the team using student-made custom parts, a commercial aluminum framing system, electrical components, pneumatic power system components, sensor components and a limited set of sub-contracted parts.

The competition theme, "Diving to the Deep: Uncovering the Mysteries of Mid-Ocean Ridges" provided an opportunity for the Genesis team to experience the excitement of working in the field of Oceaneering and underwater exploration.

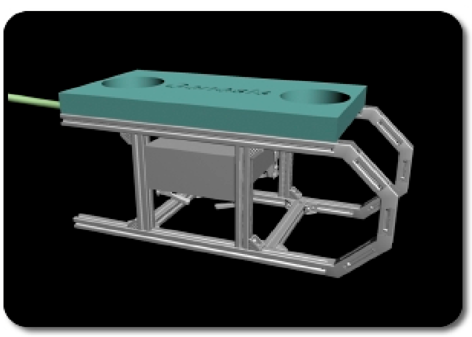

Figure A.1 – Early concept art of Genesis

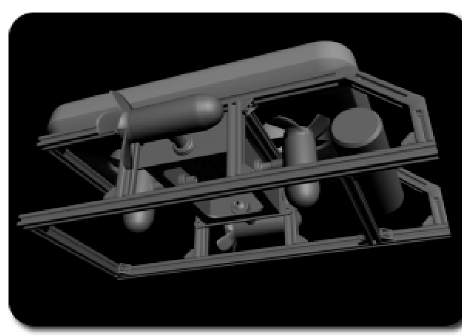

Figure A.2 – Genesis comes to life in 3D

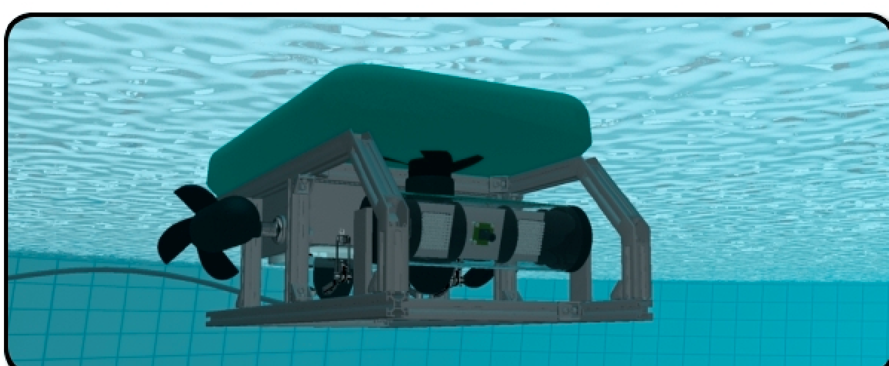

Figure A.3 – A photorealistic rendering

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1. The Team

Trevor Uptain
Team role: Team captain, technical report, arm assembly
Competition role: Mission Commander

With five years of experience building ROVs in Sea-Tech, Trevor became interested in robotics at a young age. He is a natural leader, with the self-appointed task of keeping the team on schedule. He owns and operates a web design business from his home, and is considering attending the community college when he turns 17.

Joe Thieman
Team role: Electronics, control system
Competition role: Pilot

Joe Thieman has been building ROVs in Sea-Tech 4H club since 2000. Having found an interest in electricity when he was 6, and taught the fundamentals by his dad, he has made electronic control systems for Sea-Tech's ROVs his specialty. Now, finishing his second year studying electrical engineering at Skagit Valley Collage, and having learned 5 computer languages, he has built his most complex ROV control system yet for Genesis.

Samantha McNeil
Team role: Framing, camera assembly, float
Competition role: Missions Specialist

As the instructor's daughter, Samantha has had the unique opportunity to learn about engineering first-hand. She loves to read and write, and so was naturally chosen to journal the progress of the team throughout the year. She is a home school student of sixteen, and has been in the club for five years. She has built five ROVs.

Keegan McAdams
Team role: Pressure hull
Competition role: Manipulator Operator

Keegan is a very focused member of the team. His proficiency on the lathe was an invaluable asset during the year. He attends Skagit Valley College while working part time, but still makes the time to work on the ROV during the week. He loves to work on metal, and is very good at it. He has been building ROVs in Sea-Tech for four years.

Peyton Hasenohrl
Team role: Pressure hull
Competition roll: Tether Operator

Having been in the club for three years, Peyton is the newest addition to Sea-Tech on the Genesis team. But, he has already proved himself well capable to handle the workload of building an ROV. A home school student of 16, Peyton has a variety of interests including drawing. He naturally became the artist when the team wanted to design a new part.

2. ROV Genesis

2.1 Design Rationale

Design
When a commercial company builds an ROV, they are restricted by budget and resources. Our team was also limited by these, and had the further disadvantage of meeting only once per week. In order to be completed in budget and on time, we knew that we had to keep ourselves to a strict set of guidelines. Some of our more specific goals were:

- ROV parts built by hand, rather than purchasing off-the-shelf components
- Controls systems built from scratch and customizable
- A single camera that would rotate, rather than two cameras

Missions
The missions written for the competition were unique to this year. We knew we they had to base our design on the environment we were working in, as well as on the tasks that we had to perform. Unique ideas and innovation would be essential to the design process.

Task #1: The first task requires us to free a simulated ocean bottom seismometer (OBS) from the pool bottom by removing 2-pound dive weights from its frame. The OBS is positively buoyant, so we are not required to physically bring it up to the surface. We decided to utilize a dexterous arm assembly that would allow us to make small movements rather than moving the whole ROV to grasp an object.

Task #2: In the second task we must collect three samples of ‘lava’, which are simulated by the same dive weights that hold down the OBS. To speed up our performance time we decided that, rather than simply removing the dive weights in mission #1 and placing them on the seafloor, we would deposit them into a net that we could bring up to the surface.

Task #3: Task three requests that we take a temperature reading from a simulated hydrothermal vent (see section 8). This made it necessary to create a special claw that could grip the body of the vent and give us more accurate positioning.

2.2 Engineering

Collaborative Design
Even before the Sea-Tech season began we were exchanging design ideas on our online club forum. Each member gave input as to what they wanted to see on the ROV. After some discussion we began to produce concept sketches.

In the past all of our ROVs had been constructed out of poly-vinyl chloride (PVC), a low-cost, student-friendly material. But this year, due to the size of the ROV, we decided to use mainly aluminum because of some advantages that we could see. Aluminum is a hardy material but is also lightweight. We knew that it would provide a stable construction material for our ROV, and be able to support the thrusters and pressure housing that we needed for the

Explorer class. After studying materials and discussing the various designs, we finalized the idea.

The Genesis ROV would be more traditional than previous ROVs that we had built, constructed with a wrap-around frame, foam flotation and pressure housing. The team would design a machine large enough to perform the strenuous tasks in the missions we had to perform, using high-powered thrusters to propel it. We would create a camera assembly that could rotate, and an arm assembly that would allow us to make delicate movements without powering the entire ROV. These parts are described in greater detail below.

Frame

We decided early on that we wanted our frame to be constructed out of a versatile material. Since we had very little experience in aluminum work when the year started, we decided to find a material that would allow us to interchange parts quickly. We found this in a modular framing system manufactured by Bosch Rexroth. (Figure 2.1)

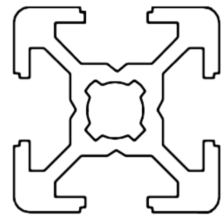

Figure 2.1 Bosch-Rexroth framing profile

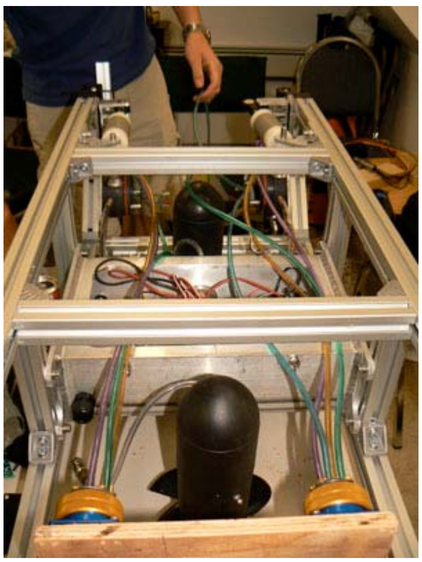

Figure 2.2 Genesis frame assembly

This framing system allows us to swap out parts with ease using a unique locking system. This way we were able to assemble our entire frame without making final commitments as to placement of parts. This made it easier to create versatile assemblies within the frame, as well as allowing us to remove parts of it to work on the pressure hull. The mounting hardware that came with the material was plentiful and easy to use, which allowed us to attach any additional items we might want to add in the future.

Pressure Housing

The pressure hull is used to house the electronics of the ROV. It is constructed out of aluminum for strength, since the thrusters are also mounted to it. It is constructed of a piece of C-channel with two specially-made aluminum plates at either end to mount it to the frame. Four aluminum discs are fitted into holes in the box to mount the thrusters. The housing is welded together with a marine weld for extra durability.

The lid for the box is made out of acrylic. It is square, with a rounded extrusion fitted with an O-ring. (Figure 2.3) The lid is held in place by four high-pressure clamps, which exert 450 kilograms of weight onto the lid. Internal air pressure can be released by a Schrader valve fitted into the box, sealing the lid further.

Figure 2.3 Pressure housing lid and seal

Two fittings with concentric ridges are connected to the hull. These are fitted with acrylic hoses that provide sealed communication with the camera housing.

Camera
Rather than simply purchasing a camera that rotated, we decided to create an entire assembly that could do so. A cast acrylic tube is mounted to two plastic end caps, and a stepper motor is installed on one side of the assembly. An aluminum plate is connected to the stepper motor and holds the camera in place. Two LED arrays, for illumination, are also mounted to this assembly. To prevent the light from reflecting back into the camera, a baffle is installed on either side of it.

Thrusters
The club was already in possession of two large trolling motors, left over from a previous project. As a result we decided to use these motors and find an extra set of them to supplement the rest of the needed power. Although this particular line of motors was discontinued, the team was able to purchase another set of them at a surplus store.

The thrusters draw 12 volts each, and are mounted to the pressure hull using struts.

Float
The ROV's float is constructed out of hydrostatic-proof polyurethane. This means that it is dense enough not to soak up water, yet light enough to be positively buoyant. It is mounted to the top of the frame with four M6 bolts. Two handles are fixed to the top of the float.

Figure 2.4 Shaped polyurethane foam float

The polyurethane came as a square block. We rounded the corners with a band saw. Since our two vertical thrusters are placed just below the float, it was necessary to cut a pair of 18 centimeter holes. We did this with the router, measuring precisely and cutting from either end. We contoured the outside of the float and the thrust tunnels to give the float a more hydro-dynamically efficient shape.

Arm Assembly
We knew that, in order to complete the missions, it was very important to create a dexterous arm assembly that would allow us to perform well under the water. We decided to create a pair of arms, using lengths of the framing material and some custom pieces.

Each arm uses three actuators for power. The first provides side-to-side movement, the second up and down, and the third forward and backward. Specially made aluminum fittings and ball joint bearings were made or purchased for smooth rotation. Manipulators are fixed to the end of the arms.

Payload Tools
In order to complete the mission tasks in a timely fashion, we knew that it was necessary to create two different manipulators. One would be used to retrieve the dive weights and hold our net, and another would be used to grasp the black smoker while taking the temperature.

The design of both manipulators is very basic and robust. Two angled grippers fit together inside of an extruded aluminum cutout. The bottoms of the pieces are slotted, and the clevis of the actuator fits inside of the slot. When the actuator pushes upward the pieces are forced apart. When the motion is reversed the claws come together. (Figure 2.5)

The second gripper is designed very much the same, but the claws have an inside radius large enough to grasp the smoker. When the arms are held at a certain position, we know we are in place to drop a temperature probe into the hydrothermal vent.

The net is made to be picked up by the first gripper. The team had previously discussed another option: would it be better to find a way to pick up the net at the ROV's center of buoyancy? After some deliberation we decided that, with the power of our thrusters, we would have sufficient strength to bring six pounds to the surface.

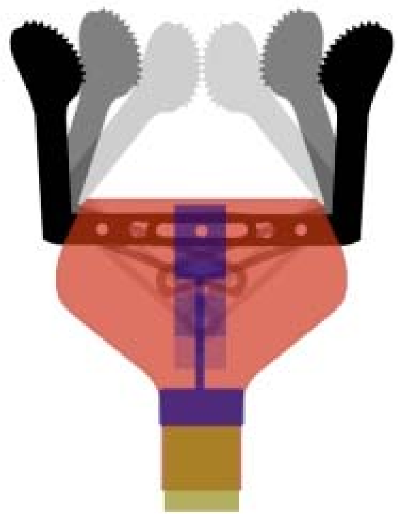

Figure 2.5 Illustration of claw mechanism

2.3 Electronics

Power
Genesis runs on 12 and 24 volts, with a safety fuse on the common ground connection. The 12 volt supply is used to power instrumentation, the camera stepper motor, MOSFET drivers, and solenoid valves. 24 volts is used to drive the main thrusters.

Communications
Data to and from the ROV is sent on an RS232 signal sent through a Cat5 data cable. RS232 was chosen over RS485 because it is compatible with the built-in serial ports still available in some laptop computers. Our system is capable of using a laptop computer as a control console, and was in fact used that way during the maiden voyage, but is primarily designed to be driven from a dedicated console. Communications protocol can be found in **Appendix A**.

On-board computing systems
The main board for Genesis consists of two PIC microcontrollers, and a PPI. The system's CPU is a Microchip PIC18F452 running at 4.9152MHz. The CPU receives incoming signals using the built-in USART, (Universal Synchronous Asynchronous Receiver Transmitter) then distributes the data to the other chips. The other microcontroller on the board is a Microchip PIC 18F1320 running at 8.0MHz. This chip takes data from the CPU and outputs low-frequency PWM (380Hz). This signal is run through a low-pass filter creating an analog

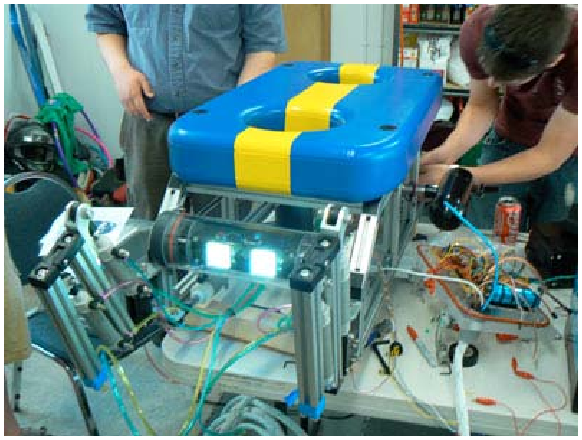

Figure 2.6 Team performing system checkouts

voltage, which is used as an input to the high-frequency PWM (20kHz) units. The PPI is an Intel 82C55A. This chip is used to multiplex the outputs of the CPU to control the inductive load outputs such as the solenoid valves. The main-board driver can be found in. The main board spec sheet can be found in **Appendix B**.

Motor Control

We built the motor controllers ourselves, using MOSFET's as our high-frequency switching device, and relays for reversing. Though an H-bridge would have taken up more space, the relays offer a fail-safe mode, allowing us to still control the motors in the case of a MOSFET clamping. This also allows for the motors to be electrically disconnected from the motor controllers during the startup period while the PWM units are still stabilizing. A circuit diagram can be found in **Appendix C**.

Programming

The programming for this ROV was done in several languages: all Windows-based programming was written in C#, while the programming for Microchip's PIC microcontrollers is written in PICBasic Pro and Microchip Assembly. A control console flowchart can be found in **Appendix D**.

2.4 Expenditure Summary

A summary of our expenses is provided below. See **Appendix E** for a detailed expense sheet. Total cost includes donations.

Frame:	**$250.00**	**Thrusters:**	**$974.82**
Flotation:	**$214.07**	**Manipulators:**	**$465.03**
Pressure Housing:	**$435.16**	**Pneumatic Arms:**	**$882.14**
Tether:	**$212.69**	**Electrical Controls:**	**$57.86**
Camera Assembly:	**$408.50**	**Total:**	**$3,900.27**

3. Challenges

As in any real-life project, there are challenges that must be faced as construction progresses. But our team feels that these challenges are how you learn. Being forced to change a plan or add a design component sparks creativity and ingenuity.

Challenge: Time

From our experience in last year's competition we knew that our greatest adversary was not the other teams. Since our club usually only meets once per week, we are often faced with being short on time. Last year our *Ranger* class ROV was not completed soon enough to compete in the water.

Solution: Rather than hoping for the best, the team decided to write a schedule and stick to it rigorously all year. Tasks would be delegated to members based on interest and skill, and those members would periodically keep the team updated on the progress of their special project. Team members also spent a lot of time working alone on weekdays that the club did not meet, as well as communicating online through a discussion forum.

4. Troubleshooting

No matter how well or long you plan, unexpected problems always arise in the testing phase of any project of this sort. Troubleshooting is a process of eliminating potential causes of those problems, resulting in the identification of the source. A systematic approach is necessary when encountering such issues.

Of course, our primary goal was to eliminate potential problems before we began construction on a particular part of the machine. When we designed our manipulator system, we simulated our design in a 3D environment. That way we could decide whether we should even pursue this particular venue. Next we mocked the claw up using wood or some other material, not to waste more expensive materials such as aluminum. If the design worked well we drew up a template and made the claw for real using the tested design. Several ideas were discarded in this manner, but it helped us to build with more efficiency and less waste.

But even with good planning problems will arise. To test controller circuitry we set up a tub and filled it with water to operate a thruster. This was the first time we had ever done this with an actual thruster. When we powered the thruster, the motor spun for half a second, gushing water out of the tub, before the controller went up in flames with a bang. The following steps were taken to determine the cause:

- The first thought was a control board error. We replaced the damaged hardware and re-tested the controller. On a small motor the system worked fine.

- We then assumed bad wiring. We tested the controller again, this time with the actual thruster, producing the same failure.

- We reviewed other possibilities and realized that this thruster was one that our club had owned for several years. Consulting with our instructor, we found out that in the past a team had taken one thruster of this size apart and put it back together again, though he was not sure *which* one.

Figure 4.1 Joe at the thruster test tank

- After more testing we concluded that this was the modified thruster based on a comparison of amperage draw between three identical units. The team apparently re-assembled it incorrectly. We repaired the control board again and tested it with a different thruster, resolving the original problem.

So what did we learn? It is important to systematically examine the possibilities when an error occurs. The process of troubleshooting can be both frustrating and rewarding, and it teaches you to think creatively and test methodically. The field experience we gain from troubleshooting may well be even more invaluable then lessons taught in the classroom.

5. Mission Strategy

Early on we decided that we needed a detailed mission strategy. From the moment we stepped up to the control shack we wanted everything to go as smooth as clockwork – we want to know what we were doing and why. This was the reason we assigned mission tasks, as well as why we wrote a strategy.

Reviewing the mission requirements, the team saw that we did not have to complete the missions in the order that they were listed. We decided to place them in an order that made more sense to us and that fit our vehicle's capabilities. We decided to complete the tasks in this order:

1. Take the temperature reading from the hydrothermal vent.
2. Dive down to the OBS and free it of all the dive weights, depositing three of the weights into a net that we will bring down with us.
3. Grab the net with one gripper and power it up to the surface.

In order for everything to function smoothly, the team knew that each person had to have an assigned task during the mission. At no time can a person in one capacity take charge of another member's assignment. We decided what role each individual would play:

Mission Commander: The Mission Commander is responsible for overseeing the entire operation. He receives information from each team member, and then makes decisions based on that information. He decides how long the ROV stays on a certain task.

Pilot: The Pilot is the driver of the ROV. He manages the control box and performs the mission tasks, but is not responsible for the operation of the manipulators.

Manipulator Operator: He is responsible for controlling the arm assembly and the manipulators. Operating eight unique functions can be a fairly complex job. He will perform the delicate movements required to collect the dive weights.

Missions Specialist: The Missions Specialist is the resident expert on the tasks the team is required to perform. She knows the mission strategy, and the most efficient way to accomplish them. She confers with the Captain when too much time is spent on one task, and is responsible for watching the sensor readings.

Tether Tender. This is a job that is more important than most give credit. The Tether must delegate the amount of tether that is released into the water. He confers with the Captain as to how much tether is let out, but is not permitted to pass on information about the ROV. He also assists with deploying the ROV.

6. Lessons Learned

However you break it down, the most important part of the project is looking back to see what you have learned. As a team we have gained experience on a myriad of tools, as well as learning how to think creatively when we decide how to tool a certain part or mount a certain piece. Although we have all worked on ROVs in the past, this year we faced new challenges due to the larger scale in construction.

Most importantly we have learned to work together as a team. We now see that conflict of ideas often lead to new ideas, which in turn leads to an improvement on the project. We had to depend on every individual to get their project done. We learned not to focus on our own ideas and inspiration, but to depend on everyone's success. Late-night work parties taught us to help each other with ideas and construction, which led to increased turnaround time from idea to final product. The invaluable experience we have gained on this project has taught us to be greater leaders and problem-solvers in the future.

7. Future Improvement

Although we are very satisfied with how ROV *Genesis* turned out, there is quite a bit of room for improvement in the future. Over the course of time we will use the skills we have gained *building* the ROV to *improve* it.

The largest improvement that we have discussed is a change of the manipulator system. Although our grippers are well capable of performing the mission tasks, we realize the value in a more methodical approach to designing and building them. The payload is extremely important – the rest of the machine is only a tool to bring these instruments to where they are needed.

We plan on creating a series of manipulators that are interchangeable with each-other. We will design the manipulators using a system that allows us to swap them out easily and quickly, yet without losing any functionality. The manipulators will come in assorted varieties, allowing us to perform different tasks with each one.

8. Plate Tectonics

8.1 Black Smokers

In 1977, scientists made an amazing discovery that dramatically affected the way they look at the world. Off of the Galapagos Islands, on a spur of the East Pacific Rise (EPR), they found a staggering structure never before known to science. At ridges along the seafloor, where the mantles that form the earth's crust are either spreading apart or being pushed together, a unique vent is formed. Seawater travels deep into the earth where it acquires minerals and chemicals, then is heated and emerges as super-hot springs. When these fluids come into contact with the cold seawater it creates hydrothermal vents. [1]

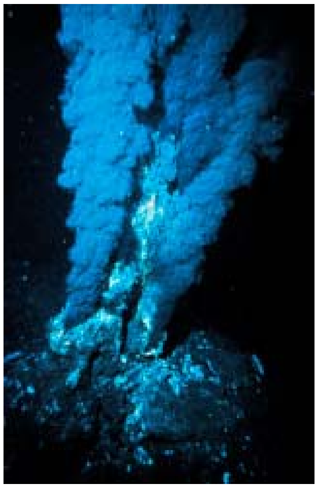

Figure 8.1 A black smoker (Courtesy of http://marinetech.org/nine_degrees/index.php)

The discovery of these vents provided unique opportunities for scientists to study the life that thrives on them. Black smokers support an amazing variety of life, especially amazing because they have, of course, no access to sunlight. Before the discovery of hydrothermal vents, marine biologists assumed that vent organisms were dependent on a “rain" of detritus from the upper levels of the ocean, like deep sea organisms are. This would leave them dependent on plant life and thus the sun. Some hydrothermal vent organisms do consume this "rain," but with only such a system, life forms would be very sparse. Compared to the surrounding sea floor, however, black smoker (Figure 8.1) zones have a density of organisms 10,000 to 100,000 times greater. [2]

How, then, do the vents support such abundant life? Scientists discovered that the vents used the process of chemosynthesis to convert carbon molecules and nutrients into organic matter. This matter provides a basis for the life that exists on and around the vents. Scientists have also discovered a species of phototrophic bacterium living has been found living near a black smoker off the coast of Mexico at a depth of 2500 meters. No sunlight penetrates that far into the waters. Instead, the bacteria use the faint glow from the black smoker for photosynthesis.

8.2 Underwater Eruptions

In 2005, a multidisciplinary research team from six institutions deployed a dozen ocean bottom seismometers (OBSs) in a few square miles on the ocean bottom at the East Pacific Rise, a divergent tectonic plate boundary located along the floor of the Pacific Ocean.[3] OBSs, though seemingly large bulky, perform a delicate job; measuring ground motions and translating them into electronic signals which are then digitally recorded. The OBSs were numbered from 201 – 212.

Figure 8.2 An OBS trapped in lava flow (Photo courtesy of http://www.whoi.edu/oceanus/view Article.do?id=27286

In April of 2006 researchers returned to the site. They planned to quickly recover the OBSs and the data they had recorded. Instead, they soon discovered that an eruption had occurred and that five of the seismometers were giving no signal. Four others were recovered, two with data intact. This meant that three remained on the ocean floor. Two months later, the researchers returned and found two of the OBSs on the seafloor, partially trapped by hardened lava flow.

It was extremely important to recover the downed seismometers. Conflicting information from the recovered instruments and lava samples had sparked a debate: did the eruption occur all at once, or was it spread out over the course of months? The remaining OBSs could contain the information that scientists rarely have a chance to pinpoint: the precise timing of an undersea volcanic eruption. Furthermore, the researchers realized that they were witnessing the birth of a new site of hydrothermal vents. Researching the area of a newly-formed vent site would give scientists the opportunity to watch the vent ecosystem being built from the ground up.

The researchers at first attempted to recover the buried seismometers using a camera-equipped sled towed by a cable behind their ship. This brought no success, and the researchers decided that it was necessary to utilize some more advanced equipment that they had at their disposal: ROV Jason, operated by the Woods Hole Oceanographic Institution (WHOI). Jason was equipped with mechanical arms and hands, hopefully capable of freeing the seismometers from the lava. In April of 2007, the researchers returned with Jason, hoping that the ROV could extricate the instruments without further damaging them or having them float away.

They found OBS 212 partially buried in lava a great distance from where it had been deployed. Recovering it would be a difficult job. But Tito Collasius and Bob Waters, Jason's manipulator operators, were up for the job. One of them removed the chunks of lava that plastered the OBS to the seafloor, while at the same time the other worked to attach a float in case the OBS tried to break free and float away. After 45 minutes the OBS was free. It floated to the surface and was recovered by the ship.

Two seismometers remained. OBS 206 was found and recovered even more quickly than 212. But OBS 210 was wedged tightly between two collapsed lava flows. They worked for several hours attempting to free it, but to no avail. They were forced to return to the surface without OBS 210. It was an unfortunate event, but scientists were elated that they had recovered two of the trapped seismometers. Jason had done well.

8.3 Conclusion

The concept of plate tectonics was spoken of in the bible [5] long before the days of Alfred Wegener or even Abraham Ortelius. But it is only recently that we have been able to extensively research the subject, with modern technology like seismometers. In the years to come scientists and marine biologists will continue to study the incredible occurrences of the processes and biology occurring at oceanic ridges. ROVs will play an important role in the future of this area of study, and it is important to educate students in areas of engineering and technology.

As we continue to learn about these and other emerging discoveries, we will gain a broader understanding of the amazing creation that surrounds us.

9. Reflections

When we started this project earlier this year, all of us had quite a bit of experience in the construction of ROVs. We came prepared for the challenge, confident that we could start and finish strong. But Genesis taught us new things, forcing us to stretch our capabilities. We found out that we had to do things we had never done before, and that the things we *had* done before were even harder to do on a larger ROV. We came into the project as individuals, and we came out as a team.

We learned to think creatively when it comes to building new equipment. We have become skilled on professional tools such as the mill and the lathe. We have learned to plan ahead and tackle obstacles. It is a great thing to look back on what we have learned and accomplished. Nothing is greater than knowing that we came through and finished strong. Genesis taught us to work harder, smarter, and faster than ever before. We are all grateful for her lessons.

10. Acknowledgements

It is impossible to conclude this report without thanking those who helped us along the journey. Without these great individuals and organizations to back us up, the completion of this project would have been impossible:

Lee McNeil, our instructor. Thanks for your expertise and wisdom.

The McNeil family, for opening up their home to us, letting us stay up late in the shop and even feeding us!

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Skagit County 4-H Leadership Council, for assistance with travel expenses

The MATE Center. Thanks for the opportunities you have opened up for us.

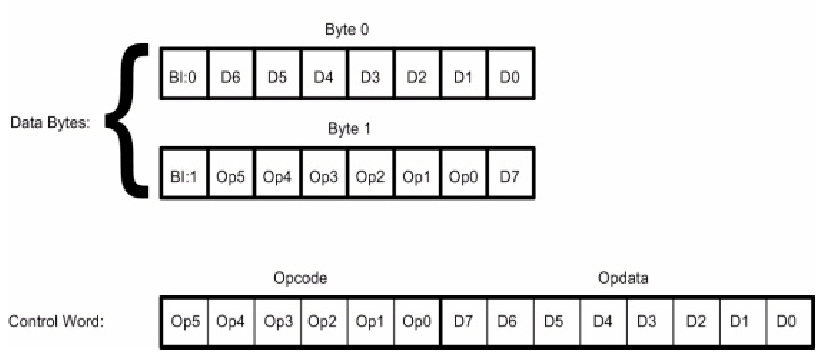
11. References

[1] http://marinetech.org/nine_degrees/index.php
[2] http://en.wikipedia.org/wiki/Hydrothermal_vents
[3] http://www.whoi.edu/oceanus/viewArticle.do?id=27286
[4] Genesis 10:25

12. Appendices

Appendix A Communications Protocol

Command word overview:
A single command is comprised of two bytes; each one containing seven bits. The MSB of each byte differentiates between the two bytes. Once received the seven data bits of each byte are assembled into a 14-bit control word made up of a 6-bit opcode and 8 bits of data.



BI: Byte indicator
Op5: Opcode bit 5
Op4: Opcode bit 4
Op3: Opcode bit 3
Op2: Opcode bit 2
Op1: Opcode bit 1
Op0: Opcode bit 0
D7: Operation data bit 7
D6: Operation data bit 6
D5: Operation data bit 5
D4: Operation data bit 4
D3: Operation data bit 3
D2: Operation data bit 2
D1: Operation data bit 1
D0: Operation data bit 0

Byte Sequence:
Byte0 (indicated by the MSB being clear) is sent first, delivering the first 6 data bits to the ROV. Next, Byte1 is sent with the 7^{th} data bit and 6 opcode bits.

When Byte1 is received the control board distributes the bits into the 14-bit control word and begins execution of the command.

Receiving Information:
Some opcodes request a return value. This value is a standard 8-bit reply. In the case of an analog sensor it will be the raw A/D conversion data.

Opcodes:
X: don't care
D: data bit

Bin	Dec	Hex	(Variable)	(Command Name)	(First Byte)	(Second Byte)
00000000	0	0x00	DDDDDDDD	Set inductive load outputs 0-7	0DDDDDDD	1000000D
00000001	1	0x01	DDDDDDDD	Set motor throttles: bits 6-7 are used to indicate which motor, while bits 0-5 are the throttle.	0DDDDDDD	1000001D
00000010	2	0x02	DDDDDDDD	Set inductive load outputs 8-15	0DDDDDDD	1000010D
00000011	3	0x03	DDDDDDDD	Set inductive load outputs 16-23	0DDDDDDD	1000011D
00000100	4	0x04	XXXXXXXX	Get value from analog input channel 0	0XXXXXXX	1000100X
00000101	5	0x05	XXXXXXXX	Get value from analog input channel 1	0XXXXXXX	1000101X
00000110	6	0x06	XXXXXXXX	Get value from analog input channel 2	0XXXXXXX	1000110X
00000111	7	0x07	XXXXXXXX	Get value from analog input channel 3	0XXXXXXX	1000111X
00001000	8	0x08	XXXXXXXX	Get value from analog input channel 4	0XXXXXXX	1001000X

00001001	9	0x09	XXXXXXXX	Get value from analog input channel 5	0XXXXXXX	1001001X
00001010	10	0x0A	XXXXXXXX	Get value from analog input channel 6	0XXXXXXX	1001010X
00001011	11	0x0B	XXXXXXXX	Software reset CPU	0XXXXXXX	1001011X
00001100	12	0x0C	XXXXXXXX	Emergency stop (shut down all outputs)	0XXXXXXX	1001100X
00001101	13	0x0D	XXXXXXXX	Hardware reset motor control microcontroller	0XXXXXXX	1001101X
00001110	14	0x0E	(unimplemented)	(unimplemented)	(unimplemented)	(unimplemented)
00001111	15	0x0F	DDDDDDDD	Ping (check for connection). Returns the operation data provided.	0DDDDDDD	1001111D

Appendix B Main Board Specifications

Features:

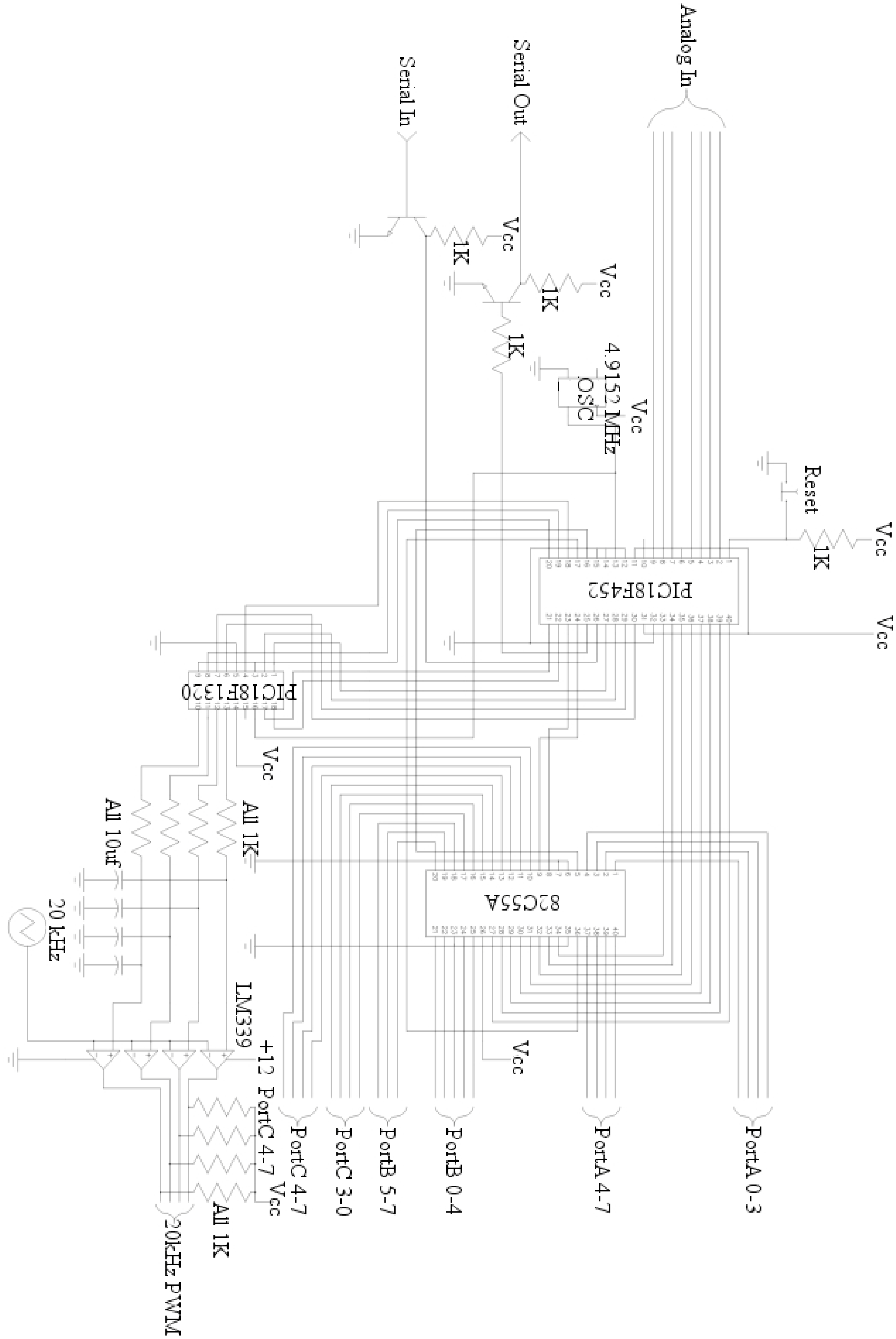
- 4.9152 MHz onboard clock
- Onboard 5v regulator
- Two 8-bit RISC based Microprocessors
- Pure hardware PWM generator
- 20 kHz PWM frequency
- Four PWM outputs
- 250 ns switching time for MOSFET drivers
- Twenty-two 200mA open-collector inductive load outputs
- Two 2.5mA digital outputs
- Seven 10-bit analog inputs
- 9600 baud serial communications
- RS232 compatible for easy interface
- Two modes of operation; Full and Failsafe
- All critical components are Mil-Spec

Components:

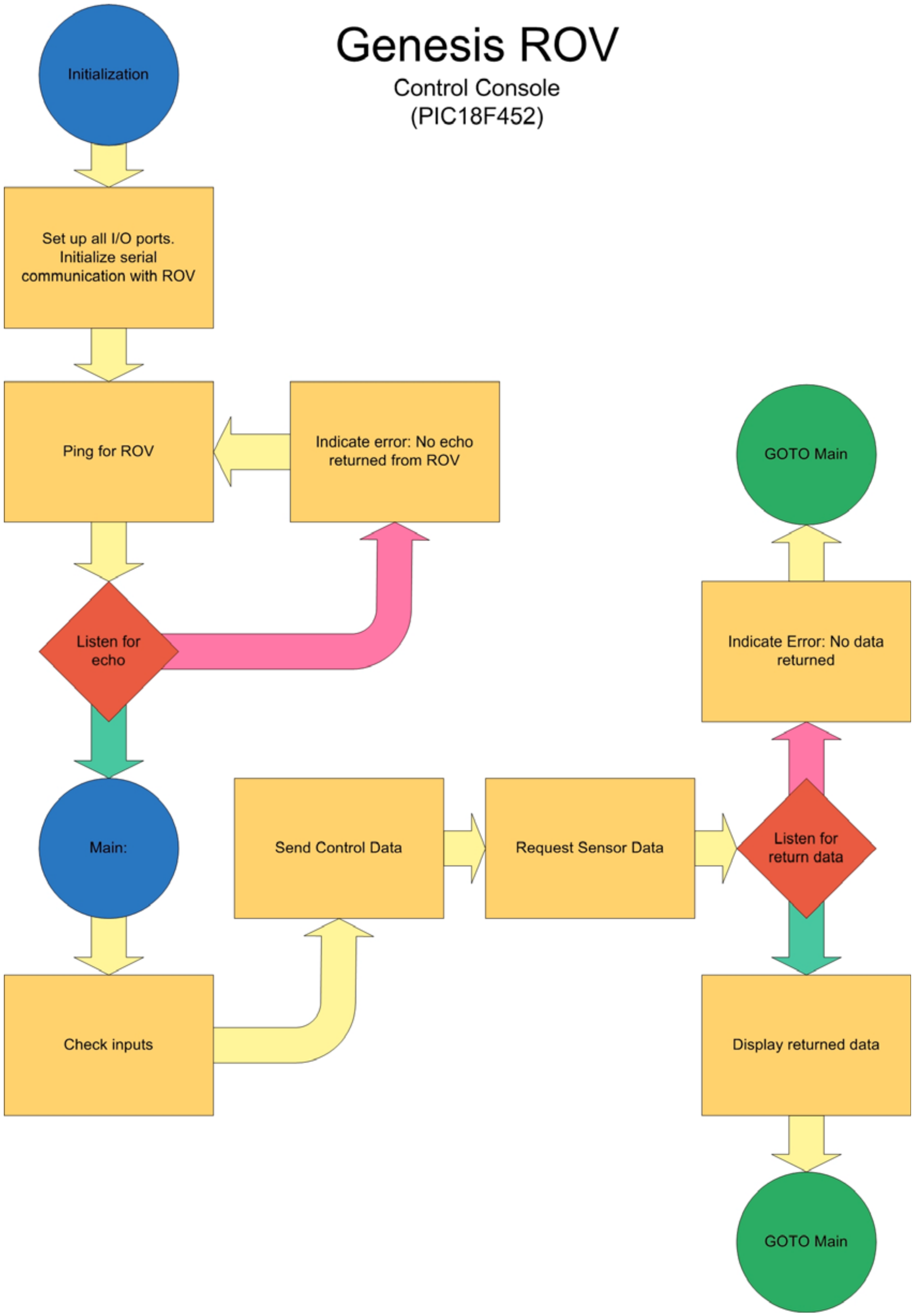
- PIC18F452
- PIC18F1220
- 82C55A
- LM339
- 2N3904
- 1N4007
- LM7805
- 1N4744
- ECA-1JM100

Appendix C Main Board Circuit Diagram

Due to size restrictions, we are unable to include diagrams of the entire electrical system. However, fuses are included in the electrical system for safety.



Appendix D Software Flowchart



Appendix E Detailed Expense Sheet

Item Description:	Part No:	Source:	Cost:	Donation:
Frame Assembly:				
Bosch 30mm x 30mm Profile x 760mm (2)	3-842-990-720-760	Pacific Integrated		*
Bosch 30mm x 30mm Profile x 660mm (2)	3-842-990-720-660	Pacific Integrated		*
Bosch 30mm x 30mm Profile x 350mm (5)	3-842-990-720-350	Pacific Integrated		*
Bosch 30mm x 30mm Profile x 250mm (4)	3-842-990-720-250	Pacific Integrated		*
Bosch 30mm x 30mm Profile x 150mm (2)	3-842-990-720-150	Pacific Integrated		*
Bosch 30mm x 30mm Profile x 100mm (2)	3-842-990-720-100	Pacific Integrated		*
Bosch 45 ° Angle Connector Kit - 30mm (4)	3-842-518-426	Pacific Integrated		*
Bosch 30mm x 30mm End Cap, Black (6)	3-842-501-232	Pacific Integrated		*
Bosch S8 dia. Self-tapping Bolt x 25mm (8)	3-842-523-970	Pacific Integrated		*
Bosch M6 Tee-nut for 8mm track (90)	3-842-501-753	Pacific Integrated		*
Bosch 30mm x 30mm Gusset Only (22)	3-842-523-525	Pacific Integrated		*
Bosch M5 Plastic Tee-nut (50)	3-842-111-988	Pacific Integrated		*
		Sub-total:	(est.)	250.00
Flotation:				
Hydro-static proof poly-urethane foam block 100mm x 460mm x 760mm; 240 kg/m^3	Last-A-Foam FR3315	General Plastics	150.90	
1.25" dia x 100mm acetal rod (4)	8497K535	McMaster-Carr	14.76	
M6 dia. stainless all-thread x 1m		Tacoma Screw	4.53	
M6 dia. Stainless cap nuts (4)		Ace Hardware	4.40	
6" x 4.03 lb/ft x 50mm aluminum channel (4)	Aluminum Assoc. CS6 x 4.03	Mr. McNeil	-	scrap
.875" dia. x .09" wall aluminum tube		Lowe's Hardware	12.95	
2 cans primer, 3 cans blue, 2 cans yellow	Krylon (assort.)	Ace Hardware	26.53	
		Sub-total:	214.07	
Pressure Housing:				
8" x 5.79 lb/ft x 360mm aluminum channel	Aluminum Assoc. CS8 x 5.79	On-line Metals	42.70	
.25" thk. x 12" x 24" aluminum plate	AISC 6061-T6	On-line Metals	70.59	
2.25" dia. x 6" aluminum rod	AISC 6061-T6	On-line Metals	23.50	
1" thk. x 8" x 12.5" cast acrylic plate		Tap Plastics	26.55	
.25" thk. x 7.25" x 11.75" cast acrylic plate		Mr. McNeil	-	scrap
Silicone O-ring: 12" OD; 1/4" x-section	9396K392	McMaster-Carr	9.47	
Destaco 500 # pull-action latch clamp (4)	Model 324	McMaster-Carr	66.40	
Hubbell nylon cord connector	SHC1038CR	WW Grainger	5.60	
Anchor Wire Seal fitting (.08" - .24")	764998 – 3/8" NPT	West Marine	12.94	
Anchor Wire Seal fitting (.20" - .47")	765000 – ½" NPT	West Marine	32.97	
Plews Schrader air valve – 1/8" NPT	38-900	Ace Hardware	3.56	
Shop hours of Heli-arc welding		Ace Hardware	-	130.00
Epoxy Adhesive		WW Grainger	2.88	
Misc. stainless steel fasteners	Metal Bond 1FBG9	Ace Hardware	8.00	(est)
		Sub-total:	305.16	130.00
Tether:				
100 ft ¾" dia. PET over-braid (white)		Buyheatshrink.com	60.00	
50' Cat IV communication cable		Club supply box	-	10.00
50' - 12ga fine braid "Monster Cable"		Skagit Whatcom	64.95	
50' composite video/power cable	EXT50	Super Circuits	14.49	
50' urethane air line w/ ¼" NPT swivels	481563	Costco	16.95	
CPC circular connector w/ boot		Allied Electronics	46.30	
		Sub-total:	202.69	10.00

Item Description:	Part No:	Source:	Cost:	Donation:
Camera and Housing:				
4” O.D. x .13” wall x 12.5” cast acrylic tube		Tap Plastics	32.55	
4” O.D. x 2.5” cast nylon rod (2)	Nylatron GSM	On-line Metals	33.22	
.25” thk. x 12” x 18” aluminum plate	AISC 6061-T6	On-line Metals	(box item)	
Silicone O-ring: 2.75" OD; 1/4" x-section (2)	9396K303	McMaster-Carr	7.40	
Mercotac 4 cond combo 4/30 amp slip ring	Model 430	Mercotac	57.00	discount
Stepper Motor:		Joe Thieman	(est)	75.00
Devcon Flexane 80 urethane	15800	Graingers	36.86	
Sony 3/8” CCD color camera	PC169XS	Super Circuits	79.95	
36 element LED Array 40mm x 40mm (2)	1156-PCB-W36	Super Bright LED	36.96	
Misc. aluminum peices		Mr. McNeil	-	scrap
Brass ¼” NPT x ¼” hose barb fitting		Ace Hardware	3.50	
¼” I.D. clear vinyl tubing x 120”		Ace Hardware	4.50	
Misc. stainless steel fasteners		Ace Hardware	25.00	(est)
Plews Schrader air valve – 1/8” NPT	38-900	Ace Hardware	3.56	
		Sub-total:	320.50	88.00
Thrusters:				
Motor Guide 22# thrust trolling motor (2)		Club supply box	-	re-used
Motor Guide 28# thrust trolling motor (2)		Lake Electric	390.00	
8” x .25” wall x 2.5” ext. aluminum tube (2)	AISC 6061-T6	On-line Metals	35.50	
Custom stainless steel machined strut per SeaTech Drawing (2 – 1 spare)	ST00310	Diversified Manufacturing	-	498.00
1-12 UNF NAS Jam nut (8)		Boeing Surplus	5.00	scrap
O-ring: 1.13" OD; 1/8" x-section (4)			-	re-used
O-ring: 1.38" OD; 1/8" x-section (4)			-	re-used
Motor Guide Ninja 7” 4-blade propeller (2)	TT124-02	Lake Electric	30.00	
Motor Guide Ninja prop nut pin kit		Angler’s Choice	16.32	
		Sub-total:	476.82	498.00
Manipulator Arms:				
Premair Air cylinder 1.50 bore x 1” stroke (2)	CDD15-SBP-030-K	Applied Industrial	-	re-used
Premair Air cylinder 1.25 bore x 2” stroke (2)	CDD14-SBP-030-K	Applied Industrial	-	re-used
Premair Air cylinder 1.06 bore x 3” stroke (2)	CDD11-SBP-030-K	Applied Industrial	83.20	
Premair Air cylinder 1.13 bore x 2” stroke (1)	CCD11-SBP-020-G	WW Grainger	57.60	
Premair Air cylinder 0.75 bore x 2” stroke (1)	CCD07-SBP-020-G	WW Grainger	45.20	
STC cylinder flow control / swivel (16)	JFC-3 – 1/8” NPT	Airtronics	40.00	
Nylon ball joint ½-20 UNC-RH (4)	1064K761	McMaster-Carr	35.72	
Nylon ball joint 5/16-24 UNC-RH (2)	1064K731	McMaster-Carr	11.30	
5/16” dia x 4” quick-release pins; SS (2)	92385A065	McMaster-Carr	70.32	
7/16” dia x 2” quick-release pins; SS (2)		Club supply box	-	re-used
1.4” dia. x 1.19 SS sex bolt (4)		Ace Hardware	24.00	
Bosch 30mm x 30mm Profile x 200mm (4)	3-842-990-720-200	Pacific Integrated	-	*
1.25 x 2.5 x 12 Delrin co-polymer block	8662K574	McMaster-Carr	37.69	
Misc. aluminum channel, PI and plate		Mr. McNeil	-	scrap
Misc. stainless steel clevis and pins		Club supply box	-	re-used
Misc. stainless steel fasteners		Ace Hardware	60.00	(est)
		Sub-total:	465.03	

Item Description:	Part No:	Source:	Cost:	Donation:
Pneumatic Controls:				
TPC dbbl. solenoid valve; close cntr (6)	DV1340-6H	Airtronics	387.00	
TPC 3-way dbbl solenoid vlv.; close cntr (6)	DV1140-6H	Airtronics	108.00	
TPC 8-station manifold block	UDVM1-40-08	Airtronics	83.20	
Twin-tec 12-port 1/8” I.D. air connector (2)	2BH-12P	Club supply box	-	re-used
STC 1/8’ NPT in-line 20 micron filter	Model AF2000	Airtronics	15.60	
Clippard 1/4” NPT Bulkhead fitting	15029-2	Airtronics	5.50	
Clippard 1/8” NPT muffler fitting (4)	15080	Airtronics	4.32	
¼” O.D. x 1/8” I.D. urethane tubing x 50’ red, yellow, purple, orange	Freeland-Wade	Airtronics	83.20	
¼” O.D. x 1/8” I.D. urethane tubing x 50’ blue, green	Freeland-Wade	Club supply box	-	re-used
.75” thk. x 10.5” x 10.5” cast acrylic plate		Mr. McNeil	-	scrap
1” thk. x 8.5” x 11.75” cast acrylic plate		Mr. McNeil	-	scrap
Silicone O-ring: 10.5" OD; 1/4" x-section	9396K390	McMaster-Carr	9.20	
Destaco 500 # pull-action latch clamp (4)	Model 324	McMaster-Carr	66.40	
Clippard #10-32 brass barb hose ftgs (48)	11752-4	Airtronics	42.00	
Clippard pressure relief check valve	MJCV-1	Airtronics	6.80	
Devcon Flexane 80 urethane	15800	Graingers	36.86	
Misc. brass pipe fittings		Ace Hardware	19.06	
Misc. stainless steel fasteners		Ace Hardware	15.00	(est)
		Sub-total:	882.14	
Electronic Control System:				
Processor chip	PIC18F452	Skagit Valley College		20.52
Processor chip	PIC18F1220	Skagit Valley College		9.30
PPI	82C55A	Skagit Valley College		11.08
Analog Comparator	LM339	Skagit Valley College		1.80
NPN Transistor	2N3904	Skagit Valley College		10.00
Diode	1N4007	Skagit Valley College		1.00
5 Volt Regulator	LM7805	Skagit Valley College		1.66
15 Volt Zener Diode	1N4744	Skagit Valley College		.76
10uf 63V Aluminum Electrolytic Capacitor	ECA-1JM100	Skagit Valley College		1.74
Printed circuit board materials		Joe Thieman		(est)
Misc connectors and hook up wire		Joe Thieman		(est)
		Sub-total:		57.86