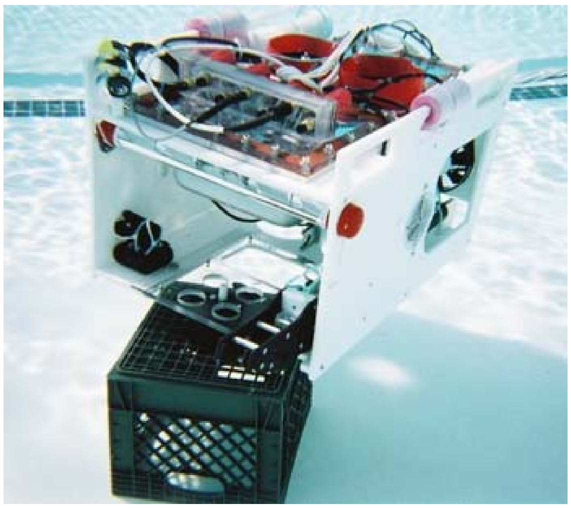
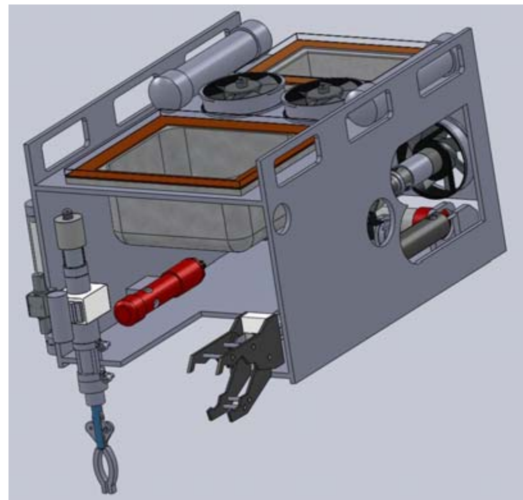
Jesuit High School Robotics Team

Carmichael, CA, United States

2009 MATE Technical Report





JSRV-04 Eripio (Latin v. *I Rescue*)

Explorer Class

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Abstract

Eripio is a highly maneuverable and powerful work class remotely operated vehicle (ROV) that was designed to meet the needs of two separate competitions. An additional goal was to design and build durable critical components for *Eripio* that are reusable on future ROVs. Taking inspiration from various professional ROVs, *Eripio* exhibits exemplary maneuverability and manipulation, ideal for the tasks at hand.

A box frame constructed from high density polyethylene (HDPE) forms the main chassis. *Eripio* has two thrusters per axis, providing six degrees of translational freedom and precise rotational control. Two manipulators provide excellent versatility to accomplish the variety of tasks required of an intervention ROV. The 40 psi pneumatic system and regulated 24 volt electrical supply will be monitored by the tether control unit (TCU). This system will ensure that a full 24 V will be available to all thrusters at all times. Onboard voltage is reduced to 12 V for the control electronics. A poolside laptop with a custom C# program will continually poll for input from two joysticks and a keyboard, communicate with the ROV, and display telemetry data.

Ultimately, our ROV was born through brainstorming, group discussions, and a demanding and structured build process. Systems were prototyped with Computer Aided Design and "Cardboard Aided Design" (mockups). The final product is well engineered and ready for two challenging competitions.

Design Rationale

Frame Construction

High Density Polyethylene (HDPE) has always been our choice for primary frame construction. The material is easily machinable, cost effective, and virtually neutrally buoyant thanks to its 0.96 g/cm^3 density. HDPE's primary drawback is its relative inability for bonding to a surface. To overcome this challenge we used various fasteners to join parts to the main frame. *Eripio's* box frame closely resembles many other professional grade ROVs, consisting of upper and lower decks fastened to two side panels. Separate watertight pneumatic and electrical control compartments are partially integrated into the frame and provide buoyancy.

Thrusters

Precise control, thrust, and efficiency were the team's primary concerns in design and placement of thrusters considering the tasks at hand. A total of six thrusters power *Eripio*, two on each axis. Four custom-built J-2 thrusters power forward and vertical motion. The addition of two translational z-axis thrusters at the center of gravity provides a full six degrees of translational motion, along with rotational control.

J-2 Thruster Design and Build

After developing the J-1 thruster and using it for a full season, we reviewed the design and made some critical changes. The thruster needed to be more reliable and easier to maintain. We determined that the thruster would leak if the motor and shaft were not directly centered or if there was any imbalance on the propeller. In order to correct any manufacturing issues the system would needed to be cut apart and completely rebuilt.

The two opposing shaft seals in the J-1 thruster were redesigned as a single shaft seal on the outside and a ceramic bearing stabilizing the rotating shaft on the inside. The bearing provides motor and shaft stability, eliminating vibrations in the shaft seal to prevent leaking.

The J-2 motors are free floating, and held in place by two steel spring wrist pins. This allows the shaft to auto-center off the ball bearing. The shaft seal, grease sleeve and ball bearing unit are all incorporated into one machined piece of Type II polyvinyl chloride (PVC). The solid stock, Type II PVC machines and glues easily, allowing for versatility and precision simultaneously. However, one drawback of the J-2 thrusters is that they are unable to be disassembled. PVC threading pieces were eliminated from the J-2 design due to the large taper that could not provide an adequate seal.

We performed testing on many of the modules prior to full assembly. We tested the J-2 thruster units for performance and reliability. See Figure 1 for a CAD (computer aided design) rendering using SolidWorks. Voltage and current were measured and a thrust profile was developed in our laboratory test tank using LoggerPro software. See Figure 2 for the results of the forward and reverse thrust profile for the J-2 thruster. A timing strobe light was used to determine actual propeller revolutions per minute (rpm) once submerged in the tank. Our results suggested that our original gearbox motors needed to be replaced with a lower rpm motor that maintained higher levels of torque. The end result was a negligible loss of rpm and better current draw. As a result of testing, we determined that a 750 rpm motor at 1.2 A was reduced to 600 rpm when submerged (80% efficient), while a 950 rpm motor at 1.6 A had its speed reduced to 660 rpm when submerged (70% efficient).

Figure 1 - J-2 Thruster Exploded CAD Rendering

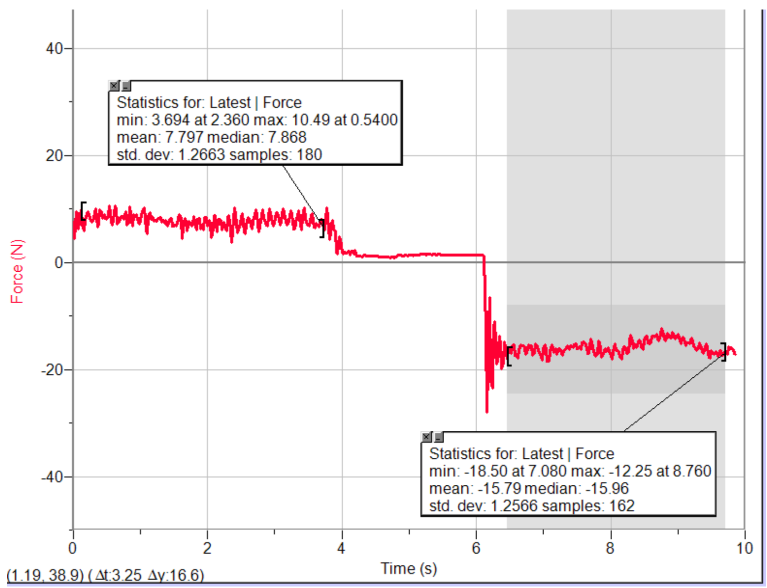

Figure 2 – J-2 Thruster Thrust Profile

The two translational thrusters face opposite sides, and, when combined, provide an average of 8 Newtons of thrust at 5 A, as shown in Figure 3. The translational thrusters are built from 750gph bilge pump motors and a radio control aircraft turbo fan prop. These thrusters are one of our numerous custom designed and built components integrated into this year's ROV *Eripio*.

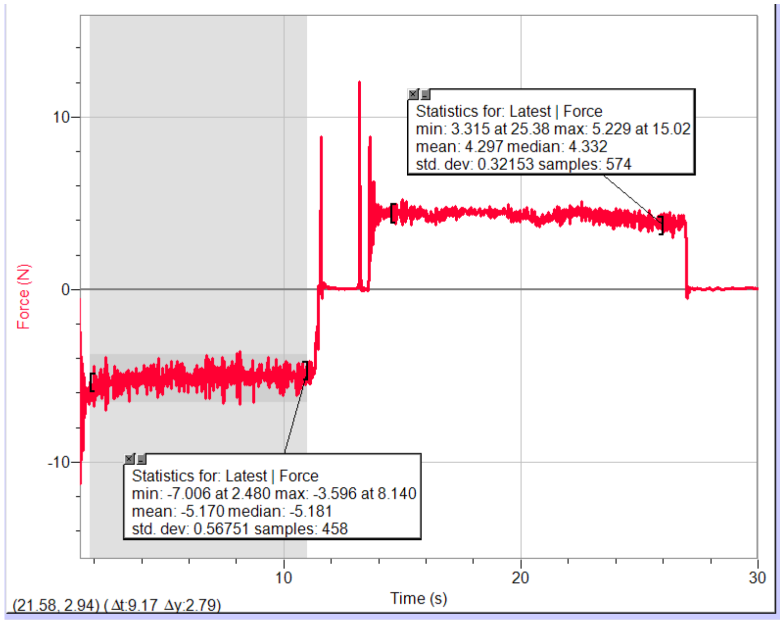

Figure 3 – Translational Thruster Thrust Profile

Tether

We had three main goals for this year's tether: neutral buoyancy, flexibility, and reusability. We achieved all three goals in our custom-built tether. The tether includes a 10 gauge, 2-conductor power line, a pneumatics line, Ethernet line for communication, composite video, shielded audio, XLR microphone line, and a temperature probe. Figure 4 shows the electrical components of the ROV tether. Buoyancy has been integrated into the length of the tether and enclosed in polyethylene terepthalate (PET) expandable braided sleeving. By using expandable sleeving and integrating the buoyancy along the length of the tether, we have developed a tether that is easier and safer to handle. Because of the components and the innovations to the tether, we believe we will have a tether that will last us for the next several seasons. Additionally, the Tether Control Unit (TCU), as diagrammed in Figure 5, has been constructed to provide a single point of interface for all connections on the tether.

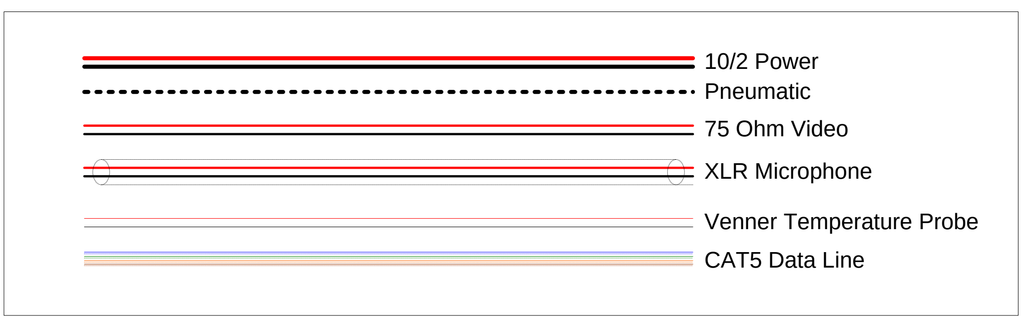

Figure 4 - ROV Tether Components

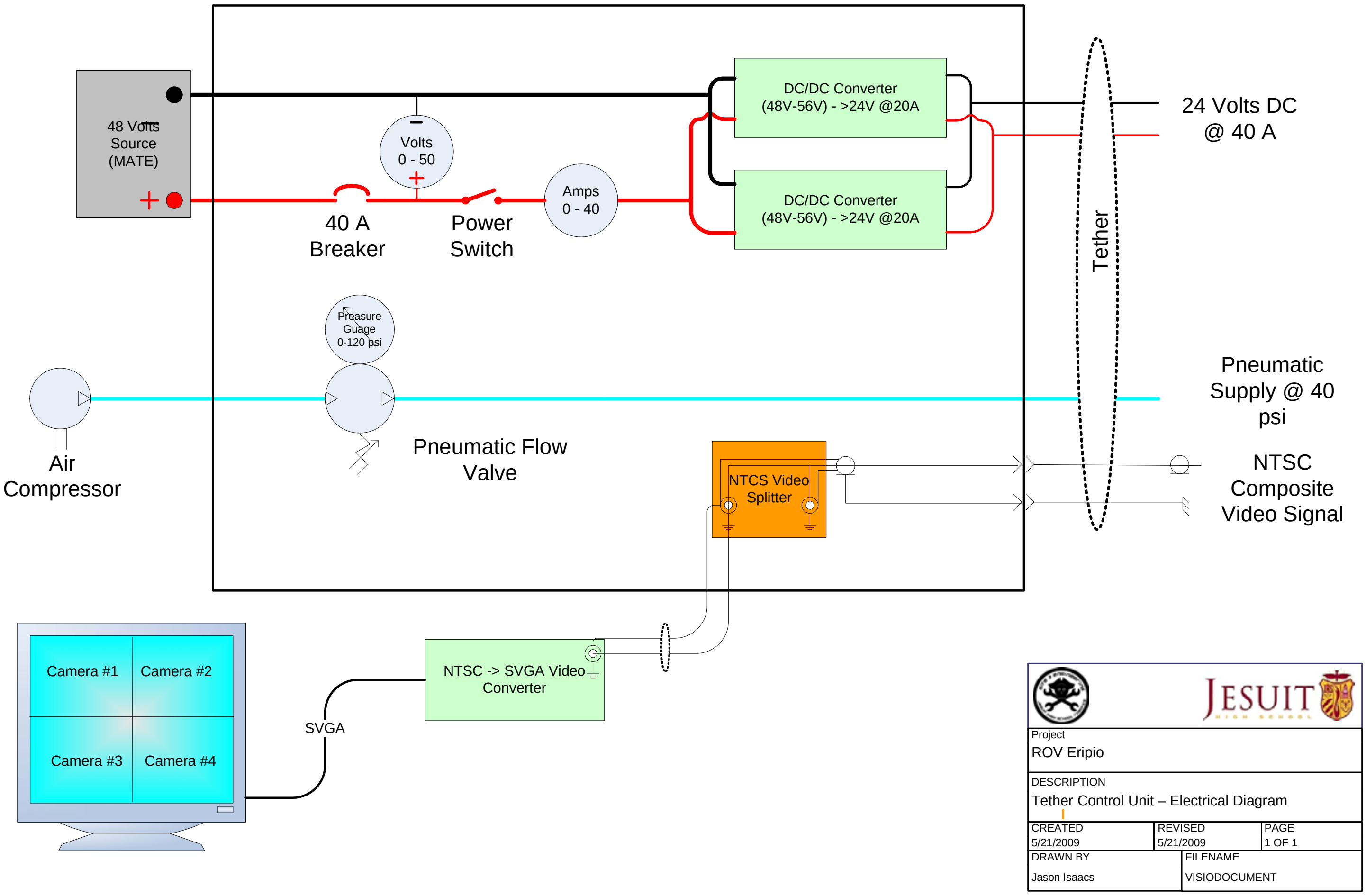

Figure 5 - Tether Control Unit Electrical Diagram

Electronics and Programming

Eripio's control system is based primarily on the Phidgets line of USB-based microcontrollers. The main Phidgets board has eight digital inputs and outputs and eight analog inputs and a USB hub. Phidget sensor boards are used to monitor voltage and current at various points in the system, as well as to provide other diagnostic information. Other Phidgets sub-boards are an 8-relay controller for pneumatics and lighting, and an 8-servo controller to interface with the speed controllers. Three Sabertooth dual 10 A PWM motor controllers regulate *Eripio*'s thrusters and the multi-axis manipulator arm's rotational motor. The electronics container also includes a 24 V to 12 V power converter to regulate power to the electronics boards, as well as the video multiplexer described below. Figure 6 shows the electrical schematic of the electronics module, and Table 1 shows the power requirements for the ROV.

With the Phidgets USB-based controllers, programming *Eripio* is simple. With the Phidgets event-based API in Microsoft C#, operating a relay or motor, or reading diagnostic information only takes one function call. On the pool deck, a laptop is connected to a USB joystick for input and a USB-over-Ethernet extension unit connects to the main Phidget board and USB hub on *Eripio*. The main program polls the joystick for input changes, and translates these into commands to send to the Phidgets microcontrollers to operate all of *Eripio*'s functions. Our software flow diagram is shown in Figure 7.

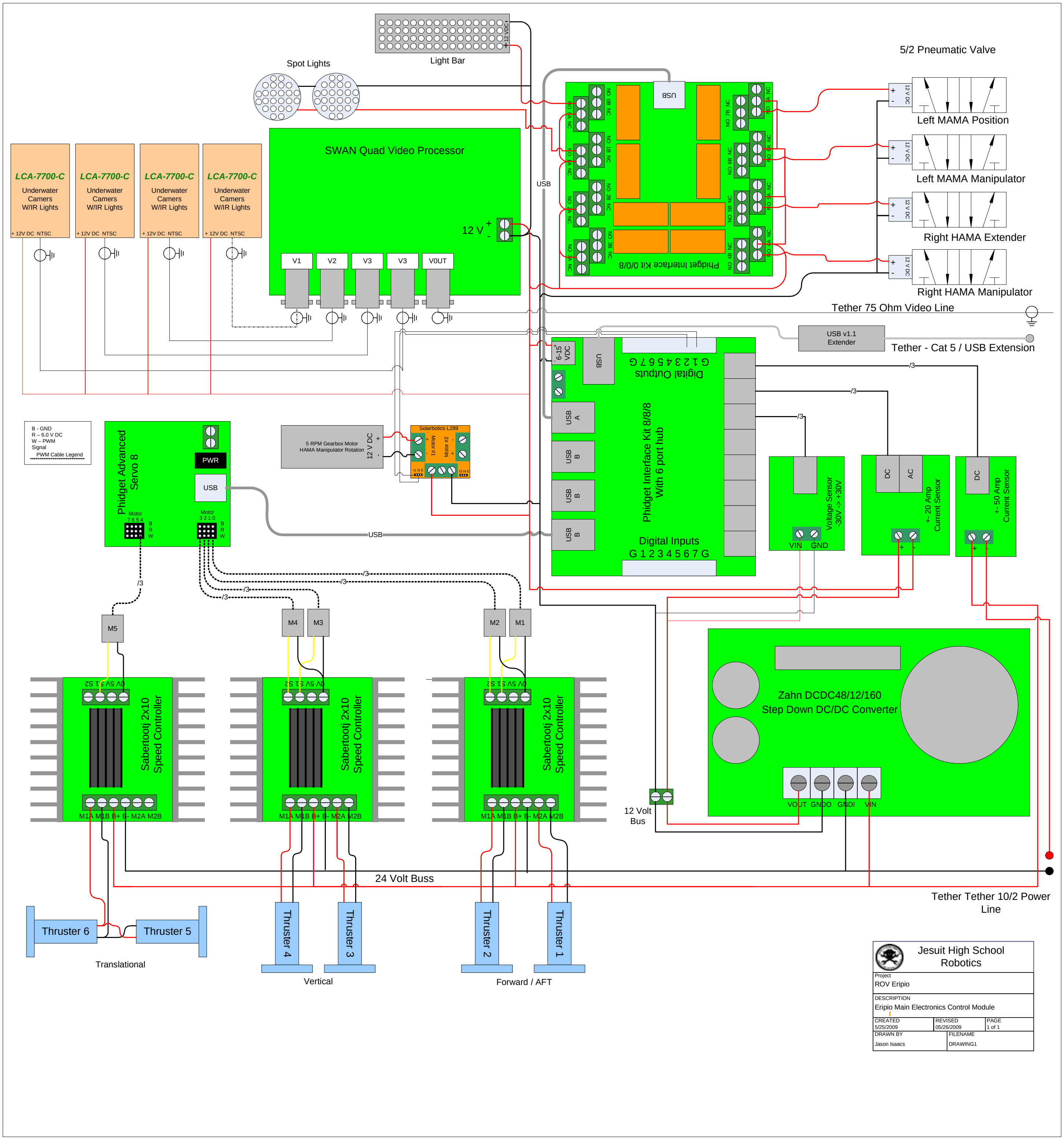

Figure 6 - *Eripio*'s Electronics Control Module Schematic

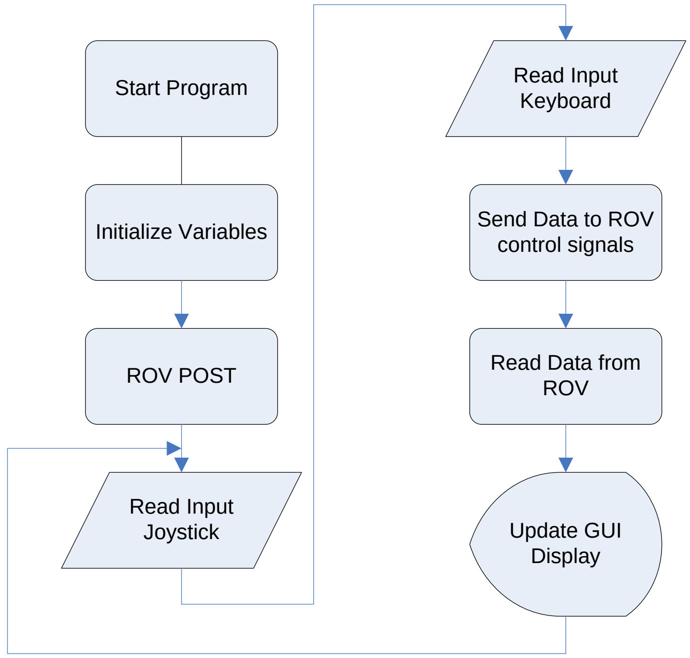

Figure 7 - Software Flow Diagram

ROV Maximum Power Requirements			
Description	**Devices**	**mA**	**mA Total**
Front Bar Lights	1	1500	1500
Rear Bar Light	1	200	200
Phidget Interface Kit 8/8/8 w/6 Port Hub	1	2000	2000
Phidget Interface Kit 0/0/8	1	380	380
Phidget Advanced Servo 8-Motor	1	2000	2000
Swann Quad Video Processor	1	800	800
LCA7700c Infra-Red Lighting	4	300	1200
SMC SY3000 Series Relay	4	9	36
J2 Thrusters’	4	4500	18000
750 GPH Bilge Pump Thrusters	2	4500	9000
	Total		**35116** **35.1 Amps**

Table 1

Video Control System

Eripio is equipped with four LCA-7700 underwater color cameras from Lights, Camera, Action Corp. These cameras have functioned flawlessly in numerous competitions, low light visibility with built-in infra-red lights. Three fixed cameras are positioned to provide clear views of the rescue skirt payload, horizontal manipulator arm, and objects behind the ROV. The fourth camera is attached to the multi axis manipulator arm, clearly showing the manipulator no matter where it is positioned. The four cameras are multiplexed into a four-channel video multiplexing board delivering thirty-two frames per second of video per channel to the surface via a new shielded video line.

Pneumatic Control System

The pneumatic system provides the control functions for the two manipulator arms and is housed in a separate watertight container. Air is fed to the ROV by a topside air compressor and regulated to 40 psi by the TCU. Four SY320 SMC relays control bi-directional pneumatic cylinders. Working with the SMC USA vendor we were able to select a cassette style relay making maximum use of space, providing enough room to add additional relays in the same container if needed. A 12-port bulkhead connection allows for the easy transition of pneumatic tubing from the inside to the outside of the container. Excess air is bled off and fed down a snorkel tube, then through a one-way valve to prevent water from reentering the system. Figure 7 shows the pneumatics diagram of *Eripio.* Although a pneumatic control system would not normally be found on a production ROV, such an arrangement directly parallels the form, function, and principles of hydraulic control systems deployed on similar work class ROVs.

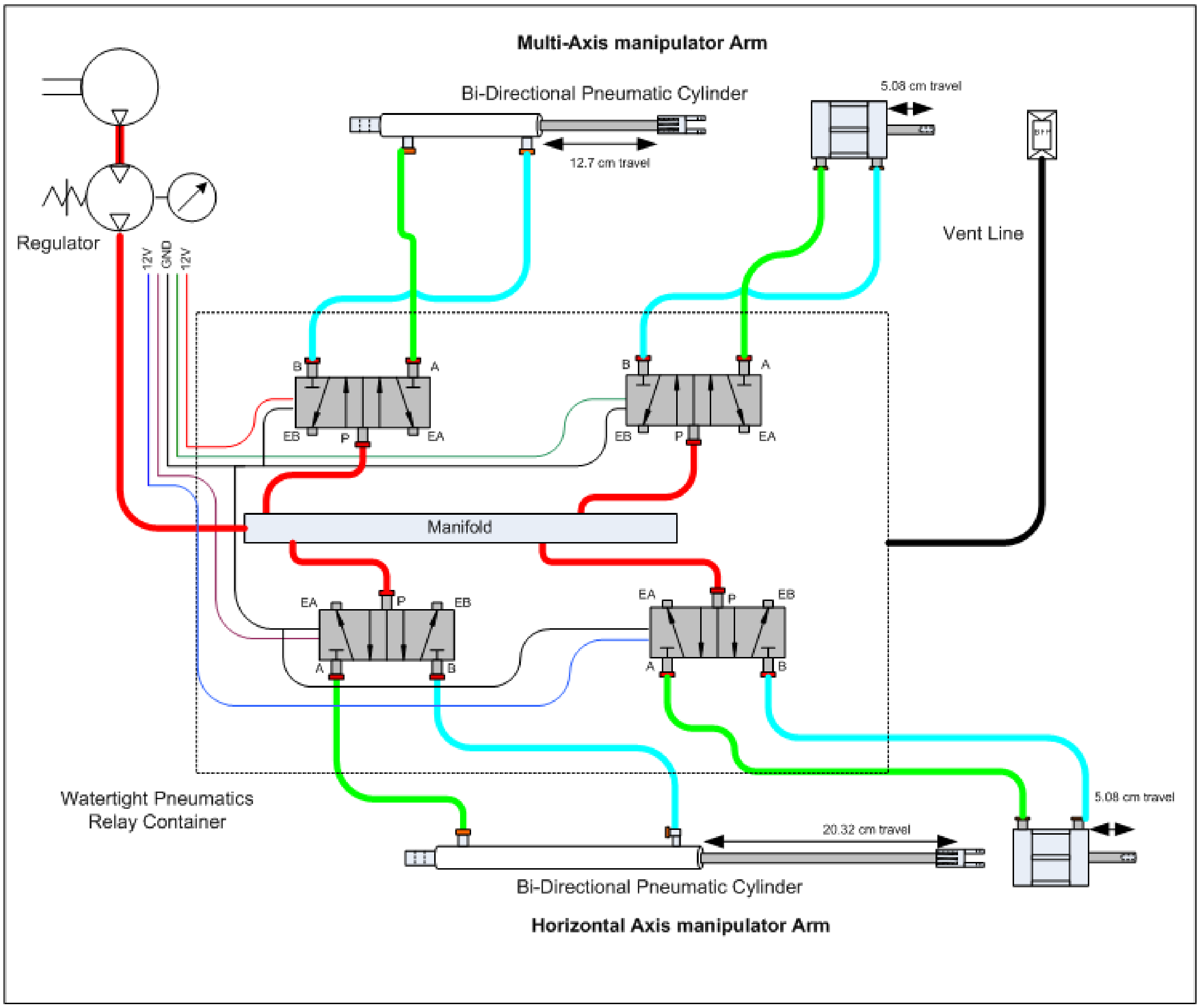

Figure 8 - Pneumatics Control Diagram

Manipulators

Two distinctly different manipulators give ROV the versatility to perform wide variety of tasks. The multi axis manipulator arm (MAMA) can have either a vertical or a horizontal orientation, operated by a pneumatic rotational actuator, and can rotate a full 360 degrees about its own axis with a 5 rpm motor. The MAMA is ideal for tasks such as opening hatches and turning handles. A second arm, the horizontal axis manipulator arm (HAMA) can extend an additional 20 cm from the main body with a pneumatic piston, enabling the ROV to extend without having to change positions. Both arms have manipulator claws operated by pneumatic pistons. Figure 9 shows the MAMA, while Figure 10 shows the HAMA grabbing an ELSS pod.

Figure 9 - Multi Axis Manipulator Arm

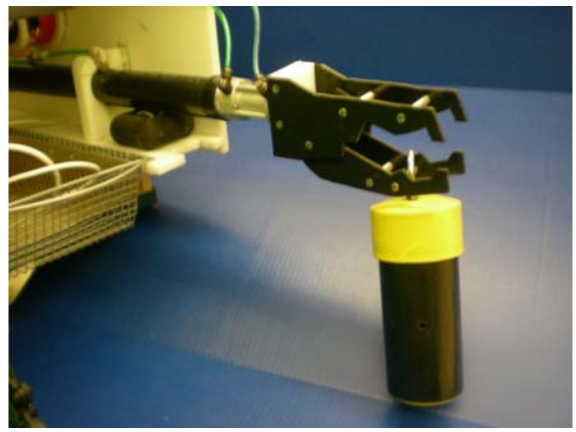

Figure 10 - Horizontal Axis Manipulator Arm

Mission Objectives

Task #1 - Survey Submarine for Damages

The low light feature of *Eripio*'s cameras provides detailed color when augmented with the high intensity LED lighting, located both forward and aft. *Eripio* is capable of producing over 12,000 lumens of lighting while only consuming 1.7 A. The cameras are placed for increased visibility of mission tasks such as surveying the submarine.

Task #2 - Deliver Emergency Life Support System (ELSS) Transfer Pods

The rotational capability of the MAMA facilitates the operation of the submarine hatch, while the HAMA was specifically designed for the task of manipulating the ELSS pods with its ability to extend and retract.

Task #3 - Air Line Insertion

The two manipulators on the ROV compliment each other in capabilities. The HAMA will open the hatch to provide access to the ventilation fitting. The MAMA, with its positioning capabilities, can handle and deliver the ventilation line to the inlet valve connection. The manipulators will also remove the airline and close the valve.

Task #4 - ROV Mating Rescue Skirt

Mating the ROV to the Distressed Submarine (DISSUB) is one of the most critical tasks to be performed. The rescue skirt, shown attached and in action in Figure 10, has been placed forward of the ROV to provide a clear view for mating with a DISSUB hatch. The addition of translational thrusters increases the maneuverability of the ROV. One of the unique features of *Eripio* is its multi-purpose payload bay centrally located in the front of the ROV. In a recent deep-sea rescue for the National Underwater robotics Challenge (NURC), the multi-purpose bay was fitted with a basket, shows in Figure 11, for retrieval of critical biological and core samples near an arctic research station. The central positioning of the payload bay and the electronics control module allow *Eripio* to be fitted easily with a variety of mission specific tools weighing up to 7 kg while maintaining neutral buoyancy by adjusting the forward ballast. *Eripio* is versatile and ready to adapt to the changing demands of an intervention ROV.

Figure 11 - Rescue Skit Payload Attachment

Figure 12 - Retrieval Basket Payload Attachment

Lessons Learned and Skills Gained

Team members have gained a variety of skills in the design, development, and building of this year's ROV project. The ROV construction this year included utilization of materials such as HDPE, aluminum, stainless steel, PVC, and Lexan, as well as the various methods for working and attaching these materials. The use of prototyping and 3D CAD software allowed us to minimize our design changes to the final systems.

We are proud of our current safety record, as we have had only one significant accident over the seven seasons that Jesuit has been competing in robotics. This is attributed to the required safety training and specific equipment qualifications. We have safety procedures and training throughout each phase of the development and operation of our ROV.

Shop Safety

- Safety goggles, gloves, and ear protection
- Scuba experience to acclimate with underwater environment
- Adult supervision at all times
- Weekly meetings including safety discussions
- Proper lab clothing and footwear required
- Fire extinguisher (ABC) and complete first aid kit in laboratory.
- Proper ventilation while working with potentially hazardous materials

ROV Safety Procedures and Implements

- Cowlings on all thrusters
- Operational check lists
- All wiring connection soldered, epoxied, and covered
- GFI protected circuits
- 40 A master circuit breaker with “kill switch”
- Designated “Safety Officer” during operation of ROV

One of the interesting skills we learned this year in the production of our poster board was the construction and use of green screen technology to create images with a transparent background for special effects. Using a free, open source image editing program called GIMP (GNU Image Manipulation Program) and Behr Candy Green paint we were able to photograph our ROV and mission props allowing us to eliminate the background. Full details of the green screen process are available on our web site, www.jesuitrobotics.org.

Trouble Shooting Techniques

Past experiences in designing and troubleshooting have proven valuable. Delivering sufficient DC power to our ROV has been a recurring problem, resulting in brown outs of our control and video systems, and underpowering of our thrusters. This year we tested the power and voltage drops on 30 meter tethers of varying gauges. Figure 12 shows our testing configuration. By using multiple multi meters to measure voltage and current at both ends of the tether, we were able to select the best combination of voltage and gauge for our new tether design. In Table 2, we have identified that the smaller the gauge of wire that is used, the lower the voltage drop will be. This table was generated using a 6 A load. Increasing the voltage and decreasing resistance by using smaller gauge wire results in better transmission efficiency.

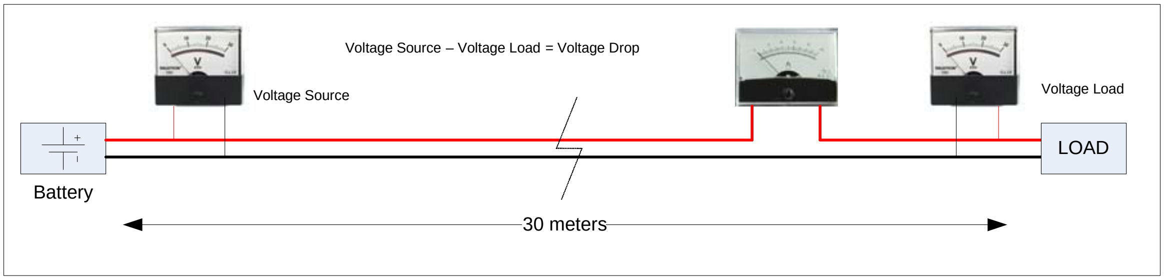

Figure 13 – Measuring voltage drop over length of tether

Wire Gauge	Voltage at Source	Voltage at 6 Amp Load	Voltage Drop
10	12 Volts	11.5 Volts	0.5 Volts (4.2 %)
14	12 Volts	10.6 Volts	1.4 Volts (11.7 %)
18	12 Volts	9.5 Volts	2.5 Volts (20.8%)
10	24 Volts	23.3 Volts	0.7 Volts (3%)

Table 2 – Voltage drop measurements of 30 meter tether

Future Improvements

This year's use of USB v1.1 for a communications protocol resulted in a very easy transition to a new set of controllers. There are practical distance limitations in the use of USB that make it impractical for a tether length greater than 30 meters. Without changing our controller architecture, we could upgrade to Ethernet to carry the control signaling on next year's ROV. Ethernet has advantages as a communications protocol. Ethernet signals can transmit multiple media types depending on the desired transmission distance. Video over IP allows for any number of cameras and allows for full pan/tilt/zoom (PTZ) control.

With the Phidgets microcontroller architecture, additional telemetry modules are simple to integrate. A pressure transducer, magnetometer, accelerometer, and temperature/humidity sensors could be added in to enhance the capabilities of the ROV.

Budget

This year's budget consisted of contributions from the school, parents, alumni, dues, and vendor donations. Travel and shipping is always a large portion of our budget and this year we set aside a part of our budget for maintaining and upgrading our shop. We added a new Smithy Granite 1324 Lathe/Mill/Drill combination unit and a battery powered band saw. Next year's plans are to purchase a new drill press, industrial band saw and a rotary table for the mill. Additionally, we took great care in the development and construction of our thrusters, electronics control module, and tether. We intend to reuse all of these components in next year's ROV to help defray build costs. A summary of our expenses is shown in Table 3.

Budget and Financial Statement		
Description		**Total**
Bulk Materials		$ 1,007.45
Electronics and Pneumatic Control Module		$ 1,370.37
J2 Thrusters (4 Production - 1 Spare)		$ 471.73
Tether / Tether Control Unit		$ 589.34
Shop Supplies and Tools		$ 4,614.35
ROV Arms and Lighting		$ 528.65
Travel, Lodging and Shipping		$ 7,837.00
	Total	$ 16,418.89

Contributions		
Description	**Type**	**Total**
Student Dues (17 Members)	$200 per Student	$ 3,400.00
Jesuit High School		$ 16,000.00
McMonagle Family		$ 1,000.00
Samsung		$ 1,000.00
Mr. Sticky	Underwater Glue Supply	$ 250.00
Subconn	Underwater Connectors	$ 500.00
Lights Camera Action	Cameras (Discount)	$ 500.00
Battery Bill	Marine Batteries (Discount)	$ 300.00
	Total	$ 22,950.00

Table 3 - Budget and financial statement

International Submarine Rescue

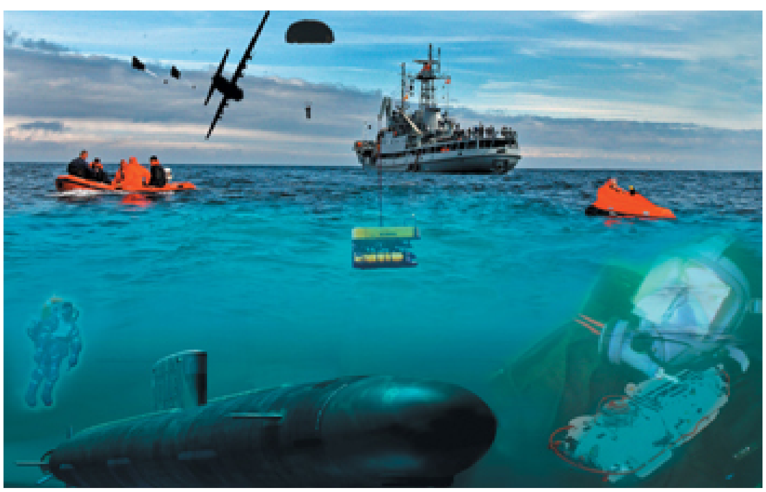

Figure 14 – Deep Sea Rescue (*Photo courtesy of Sorbet Royal 2005*)

With over forty nations now operating submarines worldwide, the North Atlantic Treaty Organization (NATO) and the International Submarine Escape and Rescue Liaison Office (ISMERLO) plan and conduct life saving exercises, providing NATO and non-NATO navies with an opportunity to train and participate in submarine escape and rescue.

While the risk of a submarine sinking is statistically low, there have been approximately 170 recorded submarine peacetime accidents in the 120 years since submarines first appeared permanently in the naval and commercial forces. During the last ten years, ten of the eighteen reported accidents have resulted in death. NATO, along with developing their own rescue platform, coordinates multi-national Distressed Submarine (DISSUB) exercises. During these exercises rescue systems and the command and control functions of submarine rescue include: remotely operated vehicles, atmospheric diving suits, air supply/ventilation systems and divers, debris removal and emergency life support store re-suppliers. All work together to complete various tasks. Submarine rescue vehicle pilots will mate with the bottomed submarine and dry-transfer personnel between the submarine rescue vehicle and the bottomed submarine.

Name	**Origin**	**Date**	**Cause**
HMS Tireless (S88),	British	12 May 2000	Reactor Coolant Leak
Kursk (K-141)	Russian	12 August 2000	Explosion
USS Greeneville (SSN 772)	American	09 February 2001	Collision
USS Dolphin (AGSS-555)	American	21 May 2002	Flooding
HMS Trafalgar (S107)	British	06 November 2002	Submerged Grounding
USS Oklahoma City (SSN 723)	American	13 November 2002	Collision
Great Wall (No. 361)	Chinese	02 May 2003	Unknown
HMCS Chicoutimi (SSK 879)	Canadian	05 October 2004	Fire
Podolsk (K-223)	Russian	14 November 2004	Explosion
USS San Francisco (SSN 711)	American	08 January 2005	Grounding
AS-28	Russian	05 August 2005	Tangled Fishing Nets
USS Newport News	American	08 January 2007	Collision
HMS Tireless (S88),	British	21 March 2007	Explosion
Nerpa (K-152)	Russian	08 November 2008	Fire
USS Houston (SSN 713)	American	01 August 2008	Reactor Coolant Leak
HMS Vanguard (S28)	British	16 February 2009	Collision
Le Triomphant	French	16 February 2009	Collision
USS Hartford (SSN 768)	American	20 March 2009	Collision

Table 4 - Reported peace time submarine accidents in the past ten years

The *Sorbet Royal 2005* challenged over 10 nations to a live submarine escape and rescue exercise. During the four week exercise, four submarines from Italy, the Netherlands, Spain, and Turkey were placed on the seabed with up to 52 men on board. Multiple rescue forces and systems, along with a wide range of rescue vehicles from the USA, Italy, France and the UK, together with Special Forces divers, medical teams, and support, worked together to solve complex disaster rescue problems in a variety of difficult scenarios. The last week of the exercise focused particularly on operational procedures and analysis of system interoperability between various rescues teams and countries.

NATO then followed with its *Bold Monarch 2008* competition. Fourteen countries participated, involving three submarines from the Netherlands, Norway and Poland positioned on the seabed to simulate DISSUB casualties. Two new rescue systems were tested: the US Navy's Submarine Rescue Diving and Recompression System (SRDRS) and the NATO Submarine Rescue System (NSRS), a multi-national project of France, Norway and the UK. While these two systems maintain the capability of mating with a DISSUB and performing a pressurized transfer of personnel to the surface, NATO rescue systems are more capable of accomplishing the same goal. The NATO NSRS has an Intervention Remotely Operated Vehicle (IROV) that can be quickly mobilized and set to sea. The IROV system locates disaster sites, detects radiation, removes debris, and provides Emergency Life Support System. In 2005, US and UK IROVs and deep diving suits logged over 100 combined hours cutting and removing hazards, which freed the Russian AS-28 mini-sub and saved seven lives.

Figure 15 - Russian AS-34 after the successful transfer of personnel

Figure 16 - NSRS onboard NoCGV Harstad

Photos courtesy of www.militaryphotos.net

The broader goal of NATO and ISMERLO is to aid in the design and development of a universal globally deployable rescue and decompression system to enable the quick rescue of personnel from a distressed submarine and return them to a rescue vessel. From the data in the past 10 years, DISSUB rescues have been multi-national efforts. Each of the events over the past 10 years has unique challenges that must be overcome with the single goal of rescuing submariners.

Reflections

This year we have seventeen members who are made up of freshmen, sophomores, juniors, and seniors with very diverse backgrounds that all contribute to the team. The breadth of this competition has allowed students to specialize in areas of programming, engineering, web design, machining, fabrication, computer aided design and modeling using SolidWorks. Junior and senior members take an active role in teaching and mentoring new members in an effort to maintain strong knowledge and continuity from year to year. This year, three seniors graduated with the practical experience gained in engineering design, fabrication, and competition as they head off to college. Each of our graduating seniors has taken away something unique this year.

Jason Isaacs

"Beyond the practical experience gained in fabricating and competing with a ROV I have gained valuable experience in leadership, engineering, and ROV piloting. In no class room could I have gained the practical experience from participating in four amazing years of participating in MATE and NURC. I plan to major in mechanical engineering and mentor Jesuit Robotics next year"

Eric Guess

"Being a part of Robotics and competing at MATE and NURC, has given me many experiences and opportunities that I would have never gotten had I chosen another path. My four years on the team have been rich and fulfilling, and I have enjoyed sharing my knowledge and skills with other teams as well as my team's younger members. I cannot thank MATE and NURC enough for the experiences that they have given me and the possible career opportunities."

Thomas Jacobi

"In my life there have been only a few meaningful things that I will always remember. I am glad to say Robotics was one of them because it gave me abilities and opportunities that are a privilege to have. I was privileged to be part of something that utilized my abilities to their greatest extent."

References

Bollard Pull
(www.hydrocompinc.com/knowledge/whitepapers/HC110-BollardPull.pdf)

Jay Isaacs, Senior Engineer
Training, Information, Mentoring

ISMERLO, the International Submarine Escape and Rescue Liaison Office
(www.ismerlo.org/)

NATO exercise Sorbet Royal 2005
(sorbetroyal2005.celex.net/)

Jane's Information Group LTd
(www.janes.com/)

SolidWorks™
(www.solidworks.com)

GIMP - The GNU Image Manipulation Program
(www.gimp.org/)

Material Data Reference Sheets
(www.tinyurl.com/JHSroboMRDS)

Acknowledgements

Jesuit High School – *Monetary donations*
Jesuit High School Technology Support – *System Software*
Lights, Camera, Action Corp. – *ROV camera support*
MATE – *Providing the underwater ROV challenge to Jesuit Robotics*
McMonagle Family – *Monetary donation*
Patel Family – *Monetary donations*
SolidWorks™ – *High school SolidWorks CAD programming*
SubConn Corp. – *Waterproof connectors*
SMC USA. – *Pneumatics cylinders, relays and vendor support*

Appendix A: Build Schedule