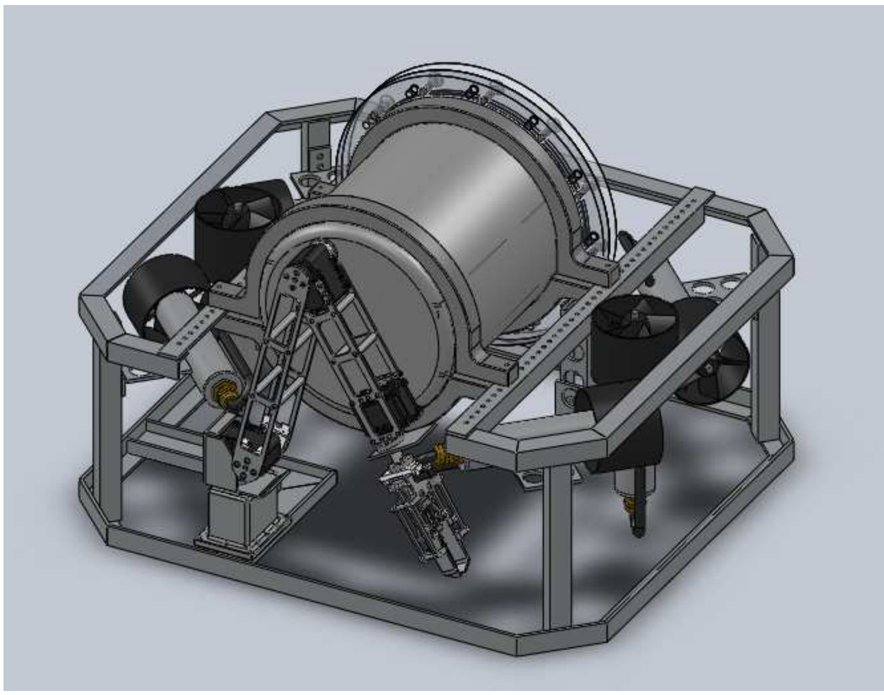
Jesuit High School Robotics Team

Carmichael, CA, United States

2010 MATE Technical Report



The Narwhal

Explorer Class

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Abstract

The Narwhal is a highly maneuverable and powerful work-class remotely operated vehicle (ROV) that was designed to meet the needs of two separate competitions, the Marine Advanced Technology Education (MATE) International ROV Competition and the National Underwater Robotics Challenge. Additional goals included designing a modular system and building durable, critical components for *The Narwhal* that are reusable on future ROVs. Inspired by various professional ROVs, *The Narwhal* exhibits high maneuverability, ideal for the tasks at hand.

The octagonal chassis is constructed primarily of extruded aluminum forming a light, yet strong frame. *The Narwhal* utilizes vectored thrust, providing translational freedom and precise rotational control. The manipulator provides excellent versatility to accomplish the variety of tasks required of a work-class ROV. The supplied 48V is utilized and converted on the ROV to 22V via a system of DC-DC converters, ensuring that accurate, stable power is available to all systems at all times. Onboard voltage is further reduced to 12V for the control electronics. A poolside laptop with a custom C# program interprets input from various control devices, communicates with the ROV, and displays telemetry data.

Ultimately, *The Narwhal* was created through brainstorming, group discussions, and a structured build process. Systems were designed with Computer Aided Design and Drafting (CADD) software, and refined with cardboard mockups, yielding a thoroughly engineered product.

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Design Rationale

Frame Construction

The Narwhal's frame is radically different from the design of previous frames. The mission scenarios necessitate a much smaller and faster ROV. The frame is constructed from welded, extruded aluminum that provides a light (1.8 kg) yet sturdy foundation for *The Narwhal*. Figure 1 illustrates *The Narwhal's* frame design. The octagonal shape and its 45-degree angles allow for simplified, vectored propulsion. The electronics container is mounted in the center of the ROV above the center of gravity. This main form of buoyancy ensures that the ROV remains stable on its pitch and roll axes. The result is an ROV that is stable, yet maneuverable enough to complete the specified tasks.

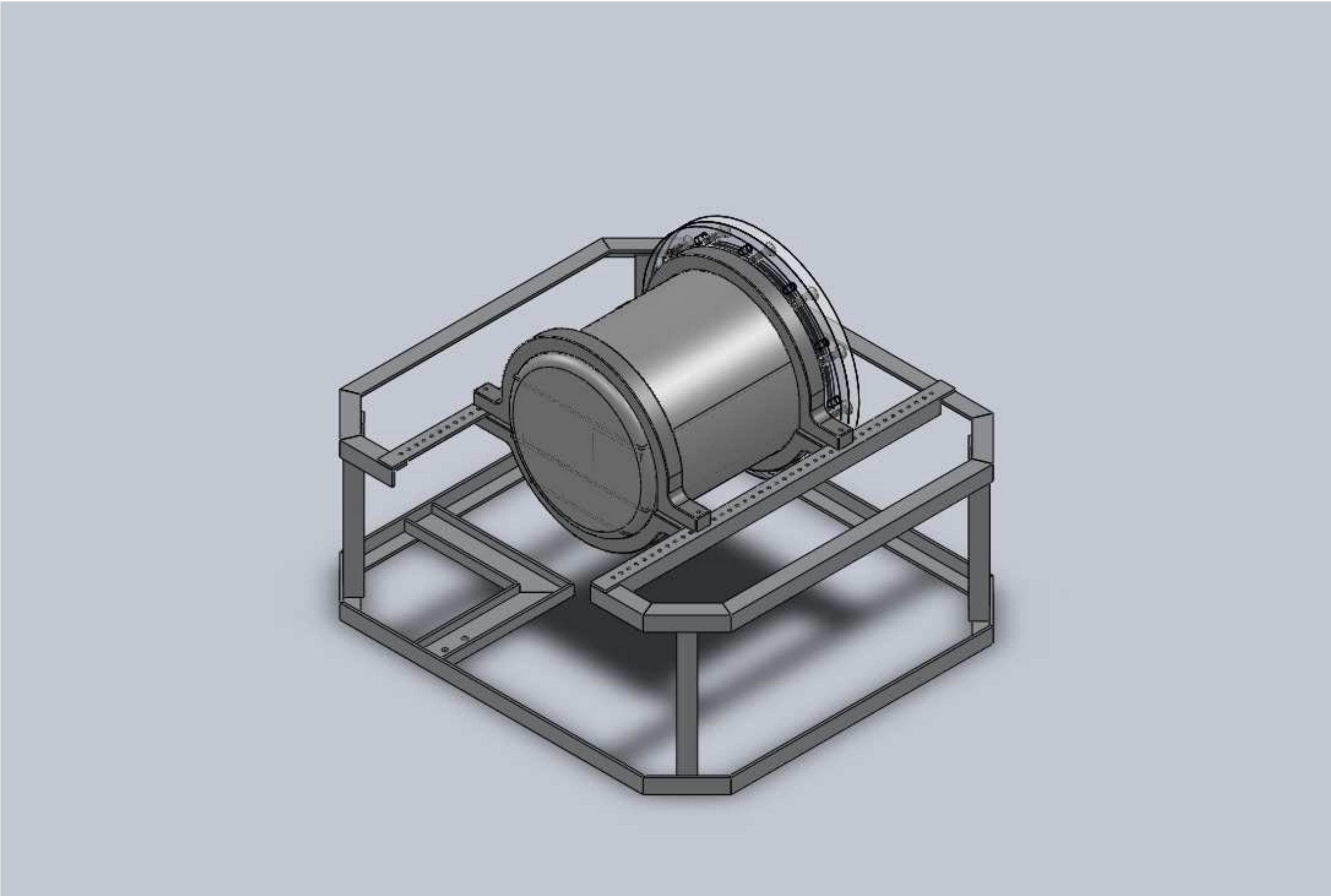

Figure 1 – ROV Chassis and Mass Properties

J-3 Thruster Design and Build

After working with custom-built J-2 thrusters last year, a design review revealed that some critical changes needed to be made this year. The primary goal was to make a smaller and more reliable thruster, accomplished by switching to brushless DC motors. The operation of brushless DC motors is unaffected if water enters the housing. This improvement requires specialized electronic speed controllers (ESC), adding to the complexity of the design.

The J-3 thruster is designed to deliver maximum power as well as precise, low-speed control. To accomplish this task, the J-3 uses a 4.3:1 planetary gear reduction and symmetric propellers. To keep the motor and output shaft stable, dual ball bearings are mounted in a custom-machined housing. A rotating shaft seal keeps water out. The motors are shrouded to increase thrust efficiency. Figures 2 and 3 show assembled and exploded views of the J-3 thruster assemblies.

Figure 4 shows the relationship between thrust and current draw of the J-3 thruster. Figure 5 depicts the relationship between thruster output and control signal (PWM) input. The data used to generate these plots is an integral part of the control software, allowing the system to determine the correct control signal for the requested thruster output.

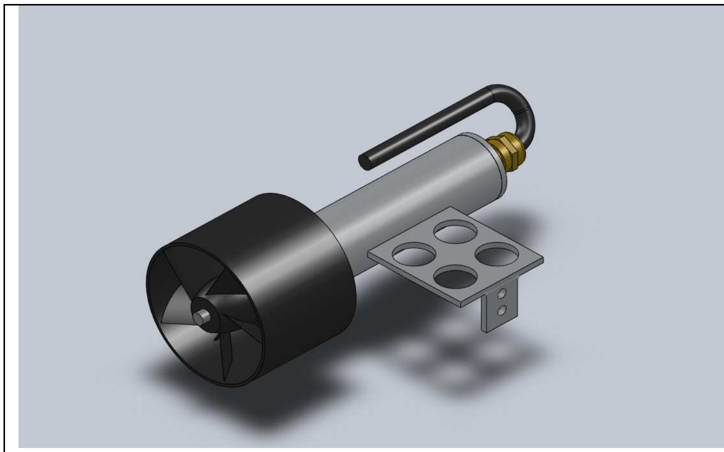

Figure 2 – J-3 Assembled Thruster

Figure 3 – J-3 Exploded Thruster

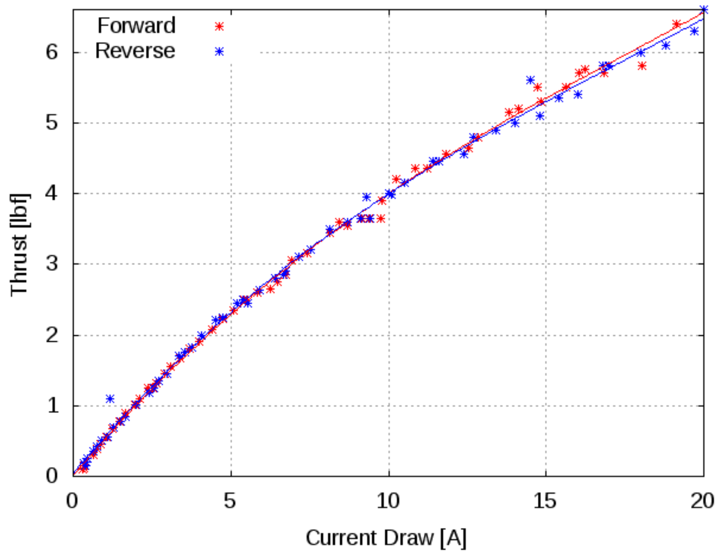

Figure 4 – Thrust to Current Profile of J-3 Thruster

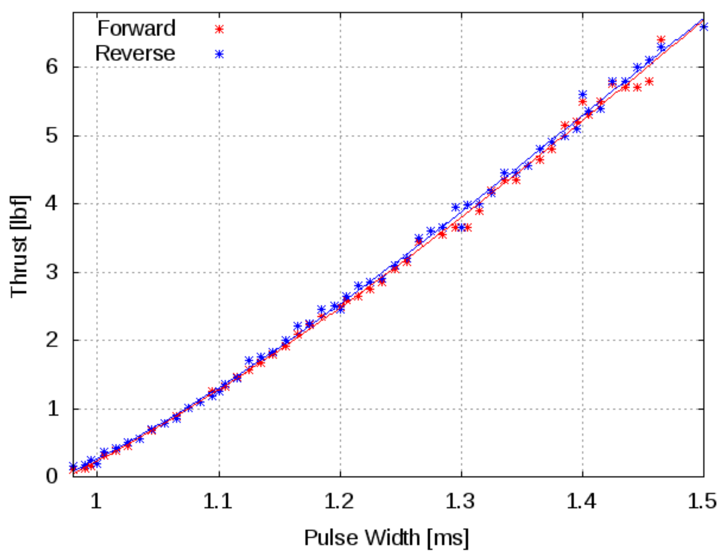

Figure 5 – Thrust vs. PWM Signal of J-3 Thruster

Tether

Two main goals for this year's tether are neutral buoyancy and reusability. Both goals are fulfilled using a custom-built tether. The tether includes a 14 gauge, 2-conductor power line, and two stranded CAT-5 lines for video and communication. The tether is shrouded in an abrasion-resistant sleeve. The tether is approximately 33 meters long. At maximum power draw, 8.5% of the available power is dissipated by the tether. Numerous foam pods placed strategically along the tether provide buoyancy compensation. Because of the components used and innovations made, the tether is expected to last for several seasons. Figure 6 shows an electrical diagram of the tether.

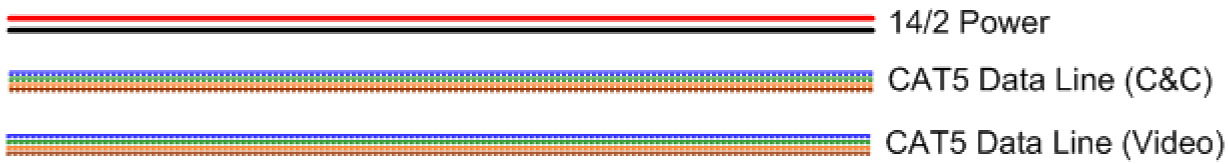

Figure 6 – Tether Diagram

Electronics and Programming

Power Conversion

A new power converter is utilized to prevent brownouts, a problem experienced in previous years. These brownouts were caused by an undersized tether running on 12V. Since 48V is provided at competition, tether power is converted to 22V using Vicor DC-DC converters, supplying the correct voltage to the motors. The converter also utilizes a 48V-to-12V Vicor DC-DC converter to power the cameras, sensors, and electronics. These converters are water-cooled to dissipate the heat generated. Table 1 shows the ROV's power requirements.

Thermal Regulation

Thermal regulation has been a problem in previous years. All of *The Narwhal's* electronics have internal protection circuitry to initiate a shutdown should the internal temperature exceeds some threshold. Water-cooling was found to be the best way to cool the electronics because there is a virtually endless supply of cool water around the ROV. The motor speed controllers are designed to be water-cooled, making integration into a water-cooling system a relatively simple task. Manufactured water-cooling blocks circulate water to dissipate waste heat. A submersible pump circulates pool water through the system.

Control Board

The Narwhal's control system is a custom design, based on a Parallax Propeller microcontroller. The Propeller microcontroller has eight separate processing cores, each controlled by a central hub. Every core has access to 32 general-purpose input/output pins. The unique features of this chip allow for each of the subsystems to have its own core, complete with its own memory. Each of the subsystems can communicate to each other through this central hub. The hub acts as the master controller for the microcontroller. The system communicates to the surface through an EIA-422 based protocol, allowing serial data to be transmitted without interference over the tether. Figure 7 shows a schematic of *The Narwhal's* electronics.

Telemetry / Drive

Each motor has its own current sensor, and the ROV is equipped with depth and temperature sensors. These telemetry devices allow the team to monitor the water temperature and ROV depth. The current sensors allow the drive system to be safely operated at high power levels without damage. Six HobbyWing 60A ESCs control the brushless DC motors used in the drive system. The electronics enclosure contains two moisture sensors to alert the team in the event of a leak.

Software

The control software for *The Narwhal* consists of two main programs. The top-side control computer has a custom written, C# program with a Graphical User Interface (GUI). The purpose of this program is to receive all control inputs, evaluate them, and translate them into a signal to be transmitted to the ROV via the tether. The GUI will constantly display ROV telemetry, ensuring that the operators are aware of the real time status of the ROV itself. Figure 8 shows the top-side control software flow diagram.

Internal to the ROV, the Propeller based control board runs a control system firmware written in Spin. With the Spin programming, software for the ROV is simplified. Open source objects for ESC control, digital servos, and serial communication are available under the MIT open license for use in the control firmware of Propeller microcontroller boards.

Hydrophone

To detect underwater sound signals, *The Narwhal* is equipped with a hydrophone. A long sound-insulating shroud is added to block out any off-axis sound waves, making the hydrophone directional. This shroud allows for a high degree of directional sensitivity that would not be attainable by simply using a hydrophone alone. To determine the frequency of the sound source being detected, a Fast-Fourier-Transform (FFT) algorithm is used on the top-side control computer, providing real-time analysis of any detected signals.

Safety Features

The following safety features have been implemented on *The Narwhal.* Cowlings placed on all thrusters protect divers, personnel, and props. An operation checklist ensures the ROV is properly inspected and configured prior to being activated. All connections are waterproofed, and all AC circuits are protected by a Ground Fault Interrupter (GFI). A 20A master circuit breaker and a “kill switch” on the ROV ensure rapid interruption of power in the event of overload or emergency. The power converter is isolated with protected connections, greatly reducing the chances of a short circuit to the frame of the ROV.

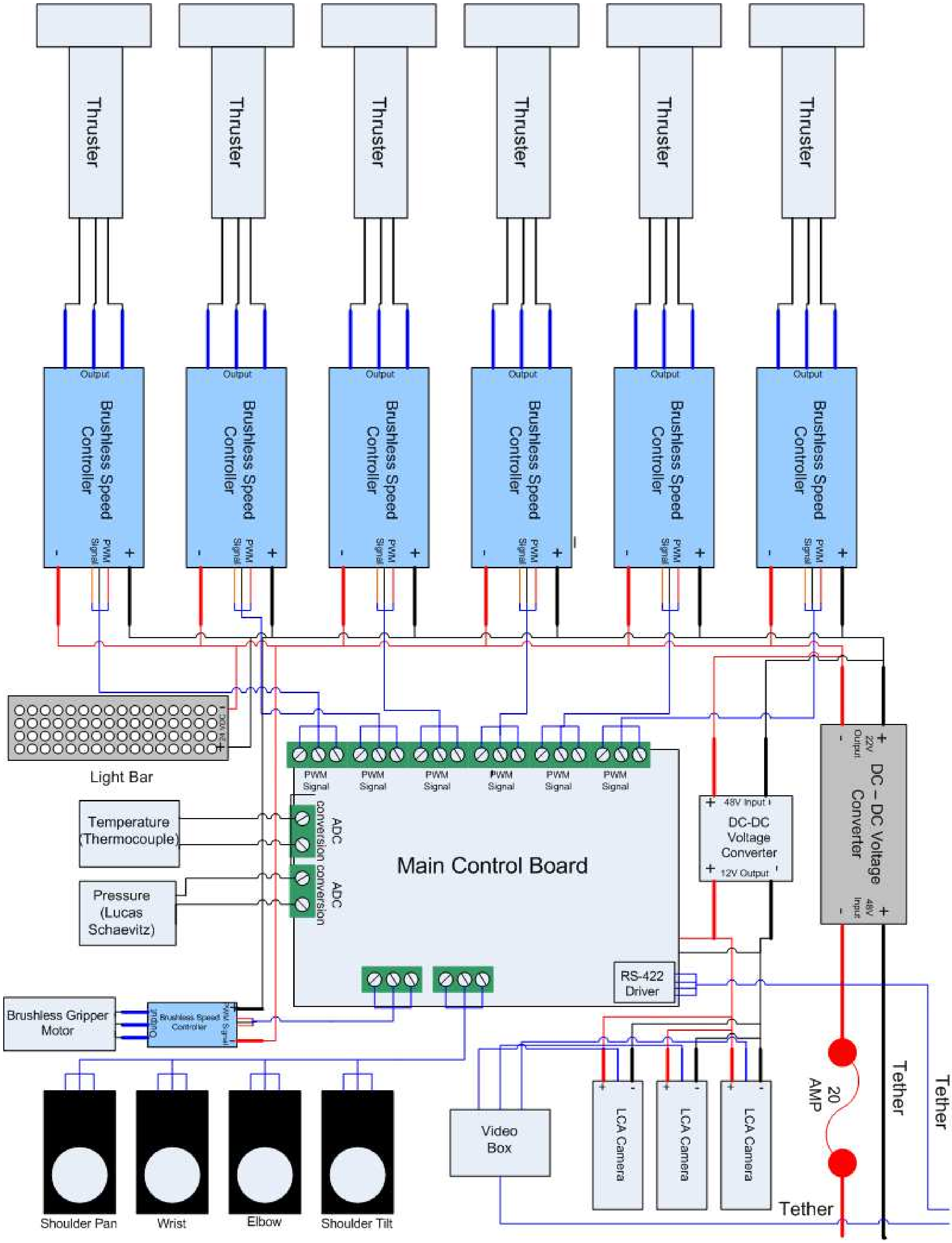

Figure 7 – Electronics Schematic

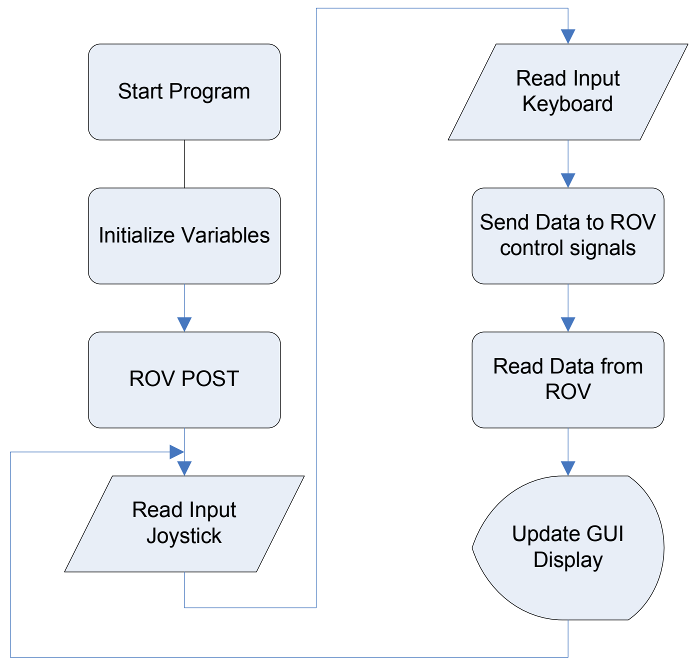

Figure 8 – Software Flow Diagram

ROV Maximum Power Requirements			
Description	**Devices**	**mA**	**mA Total**
Lights	1	1500	1500
J-3 Thrusters	6	6000	36000
LCA7700 Cameras	3	300	900
Servos	4	900	3600
Electronics Board	1	500	500
Gripper Actuator	1	3000	3000
	Total		**45.5 A**

Table 1 – ROV Power Requirements

Video Control System

The ROV is equipped with three LCA-7700 underwater color cameras from Lights, Camera, Action Corp. These cameras have functioned flawlessly in numerous competitions in low light visibility with built-in infrared lights. The three fixed cameras are positioned to provide clear views of the objects in front of the ROV, manipulator arm, and objects behind the ROV. The three cameras are converted from a composite signal to differential signal which is transmitted over CAT-5 cable. The resulting signal lines are then multiplexed on the surface to display on one monitor.

Manipulator

The multi-axis arm, shown in Figure 9, uses four Dynamixel AX-12 digitally controlled servos. These digital servos read temperature, torque load, and voltage in real time, providing precise position control. This precision control is vital as the arm is primarily designed to grasp small objects. The arm frame is cut from 5052 aluminum alloy, resulting in a sturdy and lightweight structure. The control program for the arm automatically returns it to the home position to simplify securing any collected objects for transport. The arm is waterproofed using a wire reinforced, corrugated rubber sleeve with rotating seals at the shoulder and wrist joints. The gripper (Figure 10) is actuated by a brushless DC motor so that exposure to the water will not cause any functional problems.

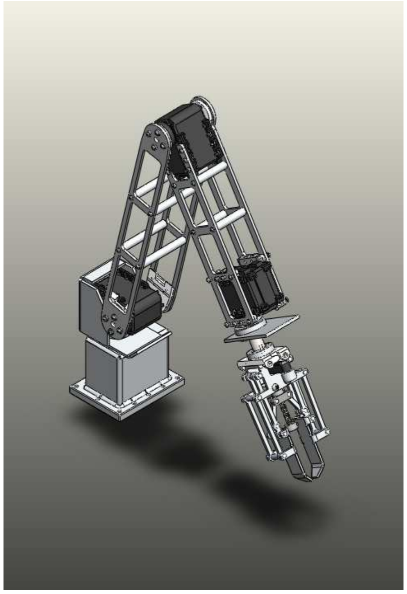

Figure 9 – Multi-Axis Manipulator Arm (No Shield)

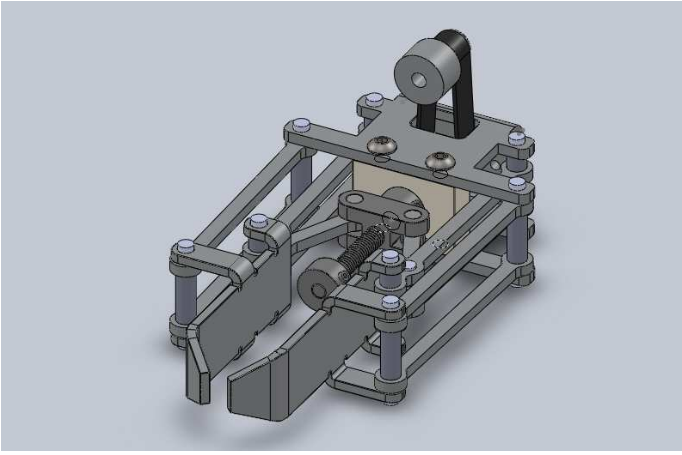

Figure 10 – Gripper

Mission Objectives

Task #1 – Resurrect Hugo

The multi-axis manipulator arm will be used for all grabbing and moving exercises required in this task. The onboard hydrophone is used to detect which buzzer is activated and then identifies the produced frequency.

Task #2 – Collect Crustacean Sample

In this task the ROV's high maneuverability will be vital, as it must maneuver into and out of a small tunnel. The vectored thrust will be essential, as it provides the precision required for this kind of navigation. The manipulator will then be used to pick up the crustaceans.

Task #3 – Sample a New Vent Site

A thermocouple temperature probe mounted to the ROV is used to measure the hydrothermal vent temperature. To measure the temperature of the venting fluid we will use a temperature probe mounted to the ROV. The multi-axis manipulator is then used to retrieve the vent spire sample and return it to the surface.

Task #4 – Sample a Bacterial Mat

After making the agar and conducting a few preliminary tests, it was determined that the adhesion of the agar to the sides of a small tube can retrieve the sample effectively. The number of tubes used was determined to attempt to collect the median volume of the target window. The collection volume of each tube was calculated based upon the diameter and depth of the sample area. Figure 11 shows the hollow tube design for agar collection.

Figure 11 – Agar Tubes

Lessons Learned and Skills Gained

Team members have gained a variety of skills in the design, development, and construction of this year's ROV. The ROV design has challenged team members to work with a diverse selection of materials, some of which were not previously used by the team. The use of prototyping and 3D CADD software has allowed design changes to be minimized in the final systems. The level of precision required by some aspects of the design also required the members of the team who are responsible for machining to refine their skills as well as require the CADD members to think through their designs more thoroughly than in previous years.

We are proud of our current safety record, as we have had only one significant incident over the eight seasons that Jesuit has been competing in robotics. This success can be 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 to 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
- Clear space around all equipment with impact resistant shields

Troubleshooting Chart

Problem	***Possible Cause***
ROV not turning on	Battery not connected. Connect Battery. Tether Control Unit not properly set up. Ensure all safety devices are not tripped, and all connections are correct. Retest. Tether not connected / Tether connection broken. Connect tether. If problem persists, use a continuity tester to ensure tether is not damaged. Repair or replace faulty wiring.
Motors not spinning	Ensure motors are wired correctly. Shorted motor coils. Verify motor wiring in electronics enclosure/motor casing.
Arm not responding.	Control software not loaded. Verify ROV control board program. Arm servo fault. Run arm servo pings. If problem persists, run arm emergency override command in control software.
ROV not responding	Ensure that tether communication and video connectors are not switched.
Motors not functioning.	Motor faulty. Replace motor and verify operation. ESC faulty. Replace ESC and verify operation.
Undiagnosed problem	Confirm power converter output to be 22V at speed controllers and 12V for electronics.

Future Improvements

Many professional ROVs have gyroscopic stabilization so they can remain stationary when subjected to an unintended force. This system would be a great improvement because this addition would allow the ROV to maintain its position while the manipulator retrieves objects. Incorporation of this feature into the electronics would be simple, as the technology is readily available.

The addition of a Pan-Tilt-Zoom (PTZ) camera system would allow for the inspection and investigation of areas without requiring the ROV to change position. In areas where maneuverability may be limited, PTZ would compensate.

Budget

This year's funding came in the form of contributions from the school, parents, alumni, team dues, and vendor donations. This year we set aside a part of our budget for maintaining and upgrading our shop. We added a new drill press, industrial band saw and numerous small tools. Additionally, we took great care in the development and construction of our thrusters, electronics control module, and tether. We intend to reuse and improve all of these components in next year's ROV to help defer build costs. A summary of our expenses and contributions are shown in Table 2.

Expenditures		
Description		**Total**
Bulk Materials		$ 1,007.45
Electronics Control Module		$ 570.65
J3 Thrusters (6 Production)		$ 1,212.14
Tether / Tether Control Unit		$ 256.87
Shop Supplies and Tools		$ 483.69
ROV Arms and Lighting		$ 528.65
Travel, Lodging and Shipping		$ 12,100.00
	Total	$ 16,159.45

Contributions - Income and Donations 2010		
Description	**Type**	**Total**
Student Dues (18 Members)	$200 per Student	$ 3,600.00
Jesuit High School		$ 14,000.00
Patel Family		$ 2,500.00
Parallax	Electronics	$ 150.00
Subconn	Underwater Connectors	$ 2,000.00
Digi-Key	Electronics Components	$ 50.00
Crate Shipment		$ 2,000.00
	Total	$ 24,300.00

Table 2 – Budget and Financial Statement

Lo’ihi Seamount

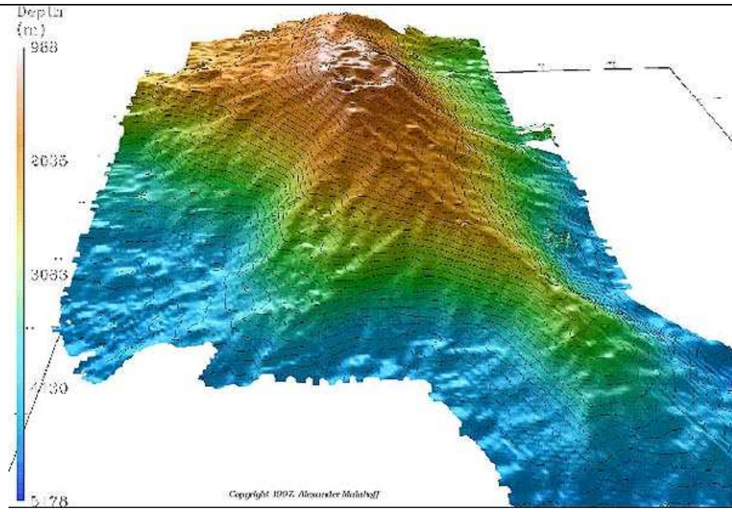

Figure 12 – Underwater Morphology of Lo’ihi Seamount

(Photo courtesy of http://oceanexplorer.noaa.gov/explorations/02hawaii/background/plan/plan.htm)

Lo’ihi Seamount, claimed to be one of the youngest seamounts of the chain, was believed to be an inactive volcano that sat upon the flank of the older, larger, and active volcano Mauna Loa. Located 30 km from the shore of Kilauea, the volcano sits 969 m below sea level. The volcano acquired its name “lo’ihi”, meaning “long” in Hawaiian, to illustrate the long and large shape of the seamount. Prior to 1996, Lo’ihi was considered inactive because the volcano remained motionless as far as records could prove. When Lo’ihi rumbled back to life in 1996, it was believed that Lo’ihi had become an active volcano once more. Once studies had begun researching the volcano under the surface, the University of Hawaii discovered that an eruption had occurred, the first confirmed historical eruption of the seamount. Due to the activity of the volcano, researchers took interest in the volcanic activity, studying the active vents that are located about 1000 m from the summit. Its lava, containing helium, is capable of being detected from distances of 2000 km of the Hawaiian Islands. The plume provides the chance of mapping the circulation of the shallow flows. The data extracted from the plume studies supports an idea of the origin of the plume being located at Lo’ihi Seamount. The studies show that the vents of the volcano are almost precisely at the same place as the water column depth as the plume maximum. The plume’s helium level is strongest near Hawaii, suggesting that the plume originates at Lo’ihi Seamount.

Research at Lo’ihi has begun because it is the youngest manifestation of what created the Hawaiian Islands and the Seamount chains. Lo’ihi has provided many research opportunities and findings, opening new possibilities and knowledge of the plume and the volcano. Lo’ihi, creating an abundance of sulfide and sulfate minerals, was the first documented occurrence of hydrothermal mineralization for ocean island volcanoes, discovered by Alice Davis and David Clague. With this finding, researchers began to use helium, magnesium, and iron as tracers to help study deep ocean circulation patterns. A success of this study later resulted when the belief of the helium flow going eastward, predicted by Stommel and Aron’s geostrophic circumion model, was proven wrong by the helium plume, which extended westward from the East Pacific Rise. The data later gathered on helium showed a linear trend created by the mixing of seawater and hydrothermal end members, all because Lo’ihi expends the heavy flow of helium. Another study performed by Stommel and Arons showed the dependency of the plume on Lo'ihi. The study showed how Lo'ihi provided a constant and steady flow from the vents of Lo'ihi around the depth of 1100 m. Because helium was obviously detectable at 1100 m, only 400 km from Hawaii, this hinted that the plume has become very extensive. This all was traced by the helium. Lo'ihi Seamount provided more than just information on the helium flow and patterns from the vents; it also provided other extensive forms of research. Researcher Ian Schipper is currently examining vescicle textures in lapilli (the physical study of the manifestation of dissolved volatiles in matrix glasses and olivine-hosted glass inclusions), the geochemical record of ascent and volatile exsolution, and the study of fine ash morphology.

The lasting beneficial effects of the studies of Lo'ihi will continue to unveil the hidden mysteries of the volcanic secrets. Researchers plan to perform future helium tests around the Hawaiian Islands to enrich the understanding of the Lo'ihi plume. The production of underwater ROVs is being used to acquire such data. An example of a successful ROV is Kakuho, which detected hydrothermal plumes from Lo'ihi, which is highly enriched in methane, magnesium, iron, nickel, copper, and helium. Because of this finding, the theory of tracers that was used to study deep water circulation patterns came about. Another example is the samples gathered by the ROV KAIKO that showed the comparisons of CO2 and 3He of vents from preactivity measurements, which suggest the creation and evolution of the Hawaiian plume, creating a shield of tholeiitic magmatism, proving that the process is still in progress. Because of the findings of Lo'ihi Seamount, the movements and patterns of volcanoes are being discovered with the help of technology and research.

Reflections

This year we have eighteen members – a team made up of freshmen, sophomores, juniors, and seniors with very diverse backgrounds all of whom bring different experiences to the team. The breadth of this competition has allowed students to specialize in programming, engineering, web design, machining, fabrication, and 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 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.

E.J. Borg

"As a four year member of The Jesuit Robotics team I have taken on roles in the Presentation and Public Relations fields. My experiences in robotics have contributed to a growing interest in the field of business. I will be attending the University of Notre Dame's undergraduate business program next year with invaluable knowledge I have gained from the MATE program."

John Taseff

"Jesuit Robotics and my specific involvement in the MATE competition have taught me volumes about the need for engineers in the world. This continual involvement in the MATE program in my four years at Jesuit has led me to Northwestern University, where I will be pursuing a degree in Mechanical engineering."

Steven Larsen

"My involvement with the robotics team in the four years I have been at Jesuit has been the common denominator in a time of great change. Every weekend the robotics team and its mentors were always there to provide training in the field of engineering – a field I will be pursuing at Cal Poly next year."

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Acknowledgements

Jesuit High School – *Monetary donations*
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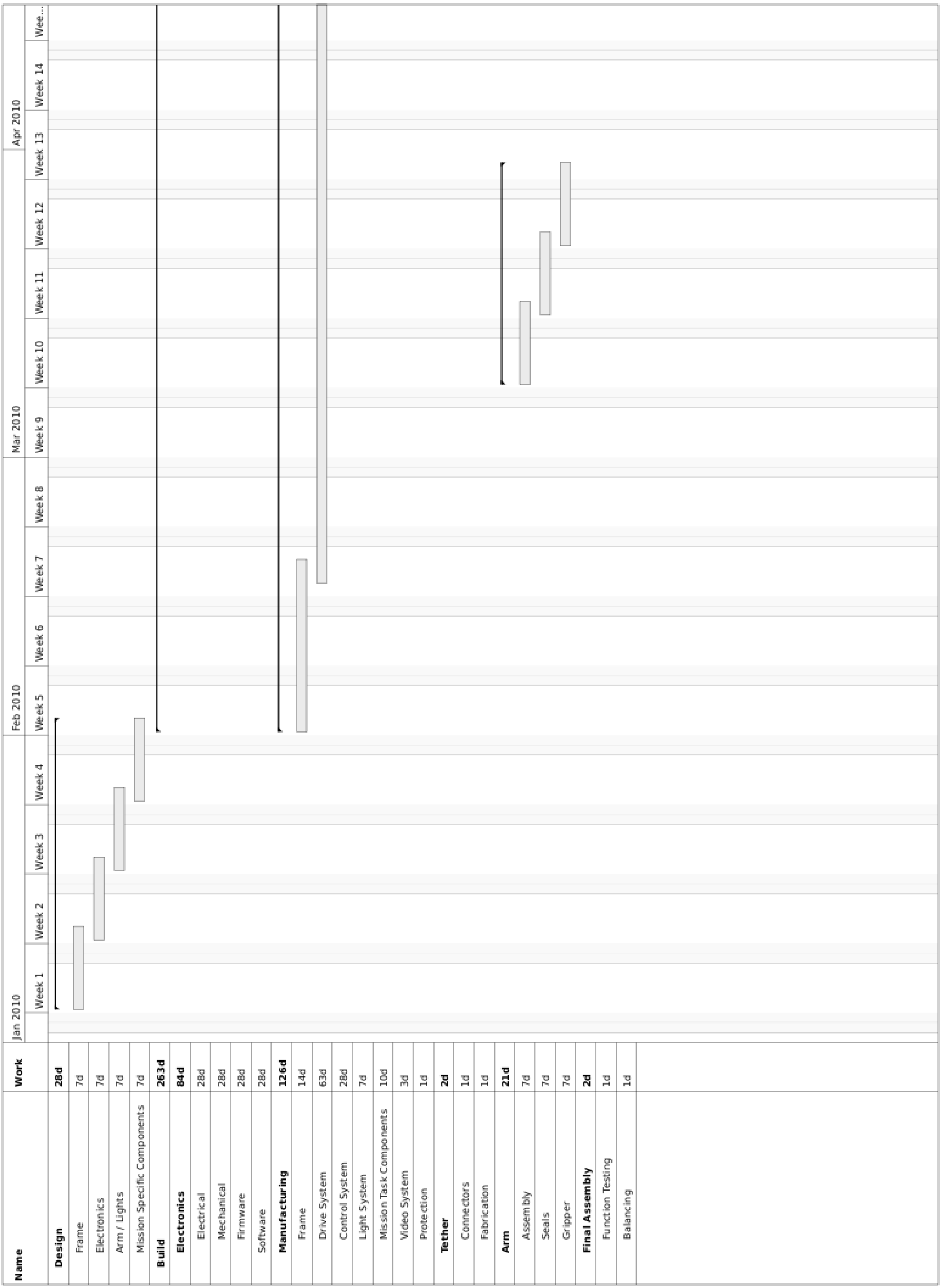
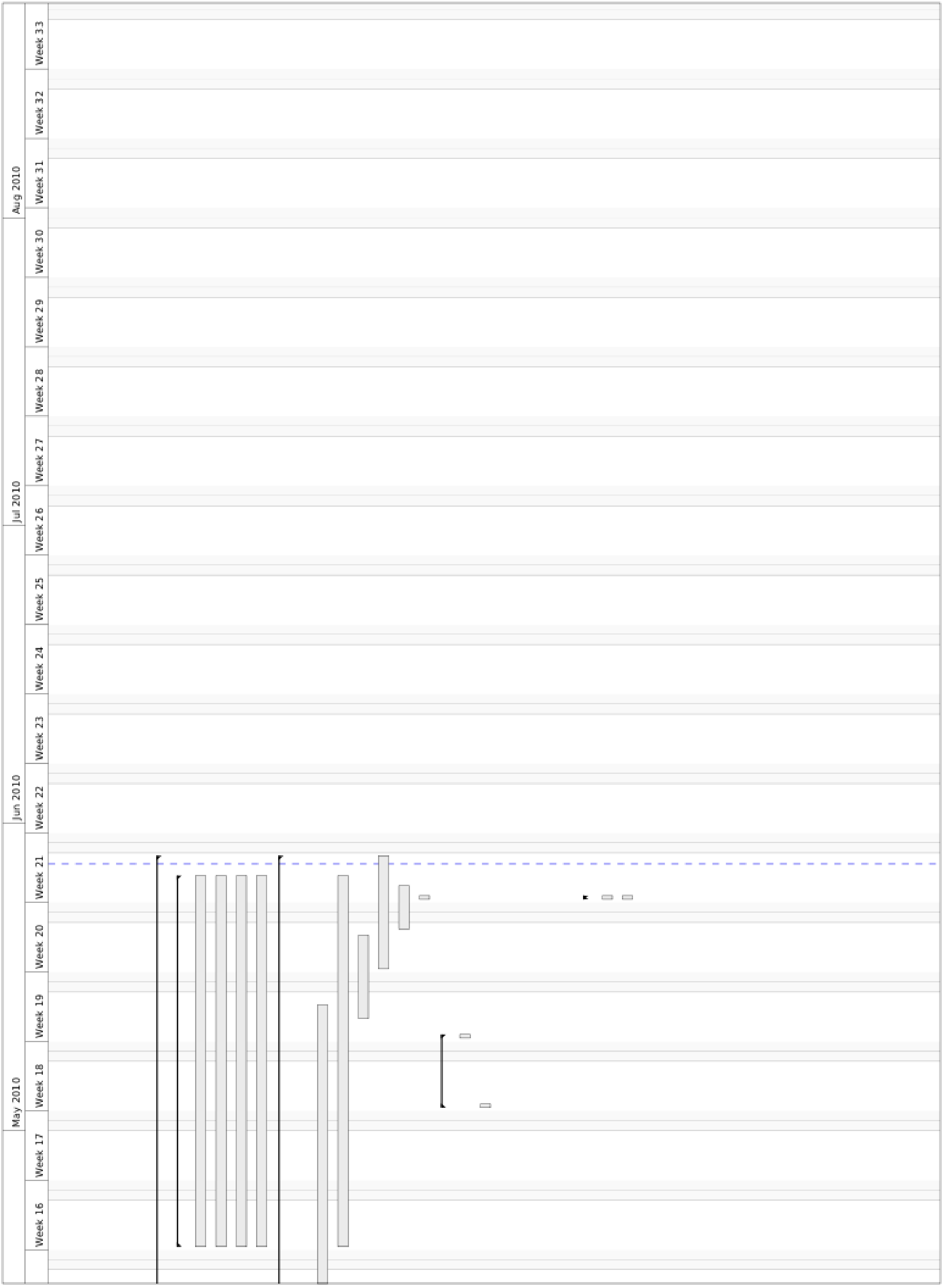
Patel Family – *Monetary donations*
SolidWorks™ – *High school SolidWorks CADD programming*
SubConn Corp. – *Waterproof connectors*

Appendix A: Build Schedule

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