FINNOVATORS

Newport High School Robotics, Newport, OR, USA

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CAD Rendering of Finnobot

Table of contents

Abstract

The Finnovators team is composed of eight seniors from Newport High School, based in the coastal town of Newport, Oregon. Over the course of several months, the team collaborated to construct Finnobot, a Remotely Operated Vehicle (ROV) with the ability to complete tasks related to commerce, entertainment, safety, and health in the ports of Long Beach, California. The first stage of the process involved designing the ROV using Inventor, a computer-aided design program. The components, most of which were originally designed to fit the specific requirements of the missions and ROV itself, were 3D-printed at Newport High School, or else purchased online. Finnobot is relatively lightweight, having been constructed out of acrylic sheets, and is equipped with a claw, motors, cameras, and an attached pressure housing, which contains electronics that correspond with the control box topside. It has been designed to work in ports and waterfronts, working in sometimes confined and often precarious conditions. Similarly, it is capable of collecting samples of sediment, locating and retrieving lost items, and building and repairing underwater systems such as the installation of a Hyperloop or maintaining the system that controls a water and light show. With these abilities, the ROV can complete tasks related to health, safety, commerce, and entertainment.

Accounting

Budget Planning

At the beginning of the season a budget was prepared with estimated expenses based on last year's actual expenses (Figure 1.1). We researched many items we were certain we were going to use and included the cost of those on the budget, such as the Raspberry Pi and Arduino Due. We planned to make a more sophisticated design this year than last, and accounted for this in the budget, giving room in the "other electronics" section especially, for we intended to use more and/or better electronics this year. Additionally, this year we wanted a control box to mount and organize all the topside electronics in, and store the ROV in, so this was included in the budget.

Our robotics club at our school supported three teams this year, for we decided from past experience that having multiple teams allowed for much greater involvement from club members; however, it additionally meant the club would have to fund three ROVs. Therefore, each team was given a limit of $1,200 to spend on the ROV. This is relatively low considering the level of complexity we were dreaming up, but it forced us to do extensive innovation and custom build a majority of our parts in an effort to keep costs down.

Item	Estimated Cost
Frame Materials	80
Pressure Housing	80
Arduino Due	30
Raspberry Pi	40
Motor Controllers	70
Motors x6	150
Other Electronics	220
Control Box	100
Cameras	40
Tether	110
Claw parts	40
Pneumatics	110
Fasteners	30
3D Printer Material	50
Bulkheads	30
Misc. Epoxy/Glue	20
Total	$1200

Figure 1.1 The above chart displays our estimated budget for Finnobot.

Project Costing

The complete budget can be seen below in Figure 1.2. The final price for Finnobot came out to be about $1,250, which was slightly over budget but still well within margins. The extra expenses came primarily from the fasteners and some miscellaneous expenses that weren't accounted for in the budget.

Our club's main sources of income this year came from our annual surplus sale and donations from regional competition supporters and friends and family. The surplus sale is an annual event where our local county government donates surplus equipment to our club to sell. This year's sale was very successful, bringing in around $6,400, and was the primary source of income for our club. Upon winning the regional competition we were given $1,000 by the Marine Technology Society, and also started a GoFundMe campaign for friends and family to donate money to help fund our trip to internationals, which has so far raised $2,000.

The travel costs for the trip came out to a total of about $7,500, which covers plane tickets and meal costs for all the team members and three chaperones, and fees for a rental house and van. The cost of airfare is $2,145, the cost of the car rental is $577, the cost of all the meals is $825 and the cost of lodging is $3,025.

Finnovators 2017 Project Costing					
	Item	Type	Qty.	Cost	Total
Frame	3/8" Stainless Steel Rod	Purchased	1	6.95	6.95
	3/8" x 18" x 48" Acrylic Sheet	Purchased	1	65.00	65.00
	Hose Clamps	Purchased	4	1.48	5.92
Electronics Housing	8" Acrylic Tube	Purchased	1	18.34	18.34
	Brass Bulkhead Tank Fitting	Purchased	2	7.95	15.90
	Gasket Material	Purchased	1	4.39	4.39
Claw	1/2" Stainless Steel Tube	Purchased	1	8.00	8.00
	Air Cylinder	Purchased	2	31.47	62.94
	Ball Bearing	Purchased	1	21.87	21.87
	Drive Belt	Purchased	1	3.57	3.57
	O-ring	Purchased	2	0.45	0.90
	Pneumatic Fittings	Purchased	1	31.50	31.50
	Rotating Tube Fitting	Purchased	1	16.84	16.84
	Stepper Motor	Purchased	1	16.95	16.95
	Torsion Spring	Purchased	1	6.05	6.05
Electronics	Raspberry Pi 3	Purchased	1	37.87	37.87
	Dual Motor Controller	Purchased	3	23.49	70.47
	Arduino Due	Purchased	1	31.37	31.37
	Arduino Due Shield PCB	Purchased	1	14.00	14.00
	Ethernet Breakout PCB	Purchased	1	5.00	5.00
	PCB Components	Purchased	1	12.00	12.00
	5v Relay	Reused	2	5.80	11.60
	700 TVL Board Camera	Purchased	3	12.95	38.85
	Composite to VGA Converter	Purchased	1	14.79	14.79
	DC/DC Converters	Purchased	2	6.99	13.98
	DRV8825 Stepper Motor Driver	Purchased	1	1.95	1.95
	Main Switch	Reused	1	3.00	3.00
	Power Filter	Reused	2	4.00	8.00
	RS232 to TTL Converter	Purchased	2	9.95	19.90
	Solenoid Valve	Purchased	1	37.12	37.12
	Video Multiplexer	Purchased	1	35.99	35.99
	LED Light	Purchased	1	6.29	6.29
	Bluetooth Keyboard	Purchased	1	25.99	25.99
	Xbox controller	Reused	1	29.99	29.99
Control Box	Box (donated by aquarium)	Donated	1	50.00	50.00
	1/4" x 24" x 36" Acrylic Sheet	Purchased	1	19.38	19.38
	Power Strip	Purchased	1	24.99	24.99
	Hardware	Purchased	1	17.00	17.00
	AC Power Inlet	Purchased	1	15.97	15.97
	Led Strip	Purchased	1	21.95	21.95
Tether	10 AWG Power Cable	Purchased	50	1.70	85.00

	Ethernet Line	Purchased	50	0.13	6.50
	Pneumatic Line	Purchased	50	0.23	11.50
Thrust	Motors	Purchased	6	16.67	100.02
	Propellers	Reused	6	6.00	36.00
Misc.	14 AWG Silicone Wire	Purchased	1	9.89	9.89
	30 Amp Powerpole Connectors	Purchased	6	1.65	9.90
	3D Printer Filament	Purchased	2	22.99	45.98
	Acrylic Cement	Purchased	1	6.06	6.06
	Adhesive Lined Heat Shrink	Purchased	1	11.89	11.89
	Epoxy	Reused	1	10.00	10.00
	Fasteners	Purchased	1	56.00	56.00
	Lubricant	Purchased	1	6.09	6.09
	Male and Female Pin Header Assortment	Purchased	1	5.00	5.00
	Plastic Screw Assortment	Purchased	1	5.99	5.99
	Silicone Sealant	Purchased	1	4.28	4.28
Total Invested in Finnobot (Purchased, Re-used, and Donated)					1262.67
Printing	Marketing Display	Purchased	2	90.00	180.00
Travel	Airfare	Purchased	11	195.00	2145.00
	House Rental	Purchased	5	605.00	3025.00
	Meals	Purchased	165	5.00	825.00
	Rental Car	Purchased	1	577.00	577.00
Club Expenses	New Shop tools	Purchased	1	2000.00	2000.00
	3D Printer	Purchased	1	700.00	700.00
	Other club teams	Purchased	2	800.00	1600.00
	Meals	Purchased	6	50.00	300.00
	Props	Purchased	1	300.00	300.00
Total Club Expenses					11652.00
Club Income	Lincoln County Surplus Sale	Income			6400.00
	Prize from Regionals	Donation			1000.00
	GoFundMe Campaign	Donation			2200.00
Leftover	Money from 2016 fund	Income			6600.00
Total Club Income					16200.00
Total Club Funds (Income - Expenses)					4500.00

Figure 1.2 2017 Finnovators Project Costing Sheet

Design Rationale

Design Process

We began the design process this year by considering our challenges in the previous season, this year's tasks, and how we wanted to allocate the budget. Different groups were then made to handle different sections of the project and a brainstorming session commenced. Many creative ideas and designs were laid out and the best were selected by weighing factors such as weight, size, effectiveness, safety, complexity, ease of manufacturing, cost, and serviceability. Next, we began writing the code and modeling many of the parts in Autodesk Inventor. Nearly the entire ROV was modeled before prototyping took place, which allowed us to assure the design would fit together as intended. Prototypes of nearly all the major components were made and adjustments were made to them accordingly. The frame was prototyped using plywood (Figure 2.1) and many of the 3D printed parts, the shrouds in particular, had to be printed a number of times before a satisfactory product was reached. Once a final version of each part was established, construction of Finnobot began. This process went quite smoothly, which owed highly to the extensive modeling and prototyping that was done.

Figure 2.1 Plywood ROV prototype

Structure

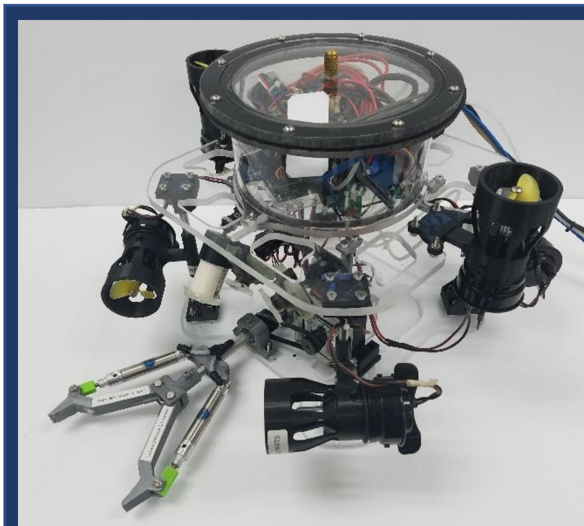

Figure 2.2 Our Completed ROV: Finnobot

Designed to be serviceable and lightweight, while not sacrificing strength or rigidity, Finnobot's frame has been built from two acrylic plates held together by four stainless steel struts. The struts are held to the acrylic plates by 3D printed clamps positioned on the corners of the ROV. These clamps hold the struts in place via two screws and allow the struts to be easily removed, which in turn makes for quick and easy repairs. The top acrylic plate integrates the electronics housing, the two vertical motors, the modular rail mounts for the cameras, and a 3D printed clamp to hold the tether. The bottom plate holds the claw and the stepper motor (which rotates the claw), and is able to be completely separated from the top plate by simply disconnecting the pneumatic line to the claw and unclamping the four struts. Additionally, the four motors used for horizontal movement are connected to the four struts via specialized 3D printed shrouds. The ample surface area provided by the plates gives lots of space for mounting components, and their positioning allows for better water flow, while still keeping the ROV small and maneuverable. Overall, the ROV is 32 x 33 x 33 cm, leaving it compact yet efficient.

Our robot for the 2016 MATE ROV competition, Ajacks, was made primarily out of PVC, and although PVC is popular for agile ROVs, we found it made it difficult to specialize the ROV. Consequently, we decided to use acrylic this year. Many advantages presented themselves as the design progressed that allured us to acrylic. It is strong, lightweight, clear, inexpensive, easy to source, easy to machine, and able to hold threads well. We also considered using HDPE, or high-density polyethylene, but while it is slightly lighter, it is more expensive, not clear, and lacks the ability to effectively hold threads.

Propulsion

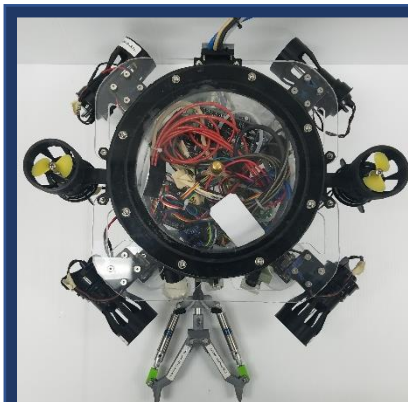

Figure 2.3 Top down view showing motors at 45°

Finnobot is propelled by six Johnson 500 GPH bilge pump motors, with two motors for vertical movement and four for horizontal movement. The four horizontal motors are mounted at 45° angles in the corners to provide a vectored layout. This means all four motors contribute to the total propulsion in all the cardinal directions, and Finnobot is therefore able to move in any direction in the XY surface plane. Last year our team employed an orthogonal motor layout, with horizontal movement being controlled by two motors. These motors were positioned on either side and parallel to the body of the ROV, meaning it was operated using tank steering. This greatly limited the range of movement of the ROV and made completing the tasks more difficult. This year we chose to use four motors for horizontal movement to increase Finnobot's versatility. From here, two configurations were possible: Finnobot could either have two motors facing in each direction, perpendicular to each other, or have a vectored layout. A vectored design was chosen because it fit our frame better, it allowed movement in any direction - including diagonal, and it provided greater thrust in the cardinal direction. For example, comparing four 45° thrusters with two parallel thrusters in each direction shows that the 45° mounting results in greater thrust: 4 * COS(45) = 2.8x thrust vs. 2x thrust.

All six of the motors are contained in custom 3D-printed shrouds, which connect the motors to Finnobot (Figure 2.4). The four horizontal motors are connected to the metal support rods of the ROV, and can rotate into the frame for sizing. This allows Finnobot to fit within the 48 cm size restriction, but still have maximal torque for movement, particularly yaw movements. It also frees up space within Finnobot, allowing for more space for tools and water flow. The shrouds have a hose clamp around them that can be loosened to rotate the motors, and tightened to hold them in place. The vertical shrouds are also removable, and are a redesign from those used at our regional competition. Previously, upward movement was impaired because the vertical motors were mounted within the top plate, so their exhaust when ascending was being pushed straight into the top plate. This oversight was corrected by moving the motors out from the top plate, so the exhaust could flow free of obstructions. The redesign made them unable to fit within the size requirement however, so they were made removable. The shrouds have tongues that insert into a 3D printed mount, which is screwed to the top plate. There is a set screw within the mount, which holds the shroud and motor in place when tightened. Making the vertical motors removable had the added benefit of freeing up space to wrap the tether. Each shroud extends 4 mm in each direction of the propeller, which both prevents the propellers from being tangled in any props and prevents accidents. Additionally, 'Moving Parts' labels are placed on the shrouds for safety purposes.

Figure 2.4 Vertical and horizontal motor shrouds

These Johnson 500 GPH bilge pump motors were chosen because our team has past experience with them so we know they are reliable, and also because they are pre-waterproofed, leaving little need for alterations. Each motor draws 3.5 amps under full load, meaning if all six are fully activated they will draw a total of 21 amps.

Cameras

Finnobot is equipped with three 700TVL CMOS board cameras, which allow the pilot to view the ROV's surroundings. One camera records the claw movements while the other two provide forward and reverse views for navigation. Having a camera view of the claw is vital while completing tasks such as collecting sediment samples or installing the frame onto the baseplate. The forward and reverse cameras are also crucial because they help the pilot know what obstacles are around the ROV, increasing spatial awareness. The forward camera also has a slight view of the claw, and gives a second perspective on its location, which is quite helpful when making precise movements.

The cameras can be easily adjusted if different viewing angles are desired using the 3D-printed modular rail mount system (Figure 2.5). This mounting system involves three different parts, the rail, the camera mount, and the joint. The rail connects to the top plate and has a slot 16 cm long that the joint can mount to. The camera mount holds the camera in place with a set screw and on the opposite side has a ball 2 cm in diameter protruding from it. The joint has a corresponding socket into which the ball is inserted; when the screw within the joint is tightened it holds the camera securely in place, and when it is loosened the camera can be adjusted. The ball and socket system allows for a wide range of viewing angles to be accessed with quick and easy adjustments.

Figure 2.5 Camera Mount

To waterproof the cameras, a small acrylic plate was glued to the cameras' lenses and the cameras themselves were cast in epoxy using a silicone mold. First, the cameras were each tested and focused, and then a small piece of 0.5 cm thick acrylic and 2.5 cm square was glued to the lens using JB Weld. This process had to be done with the utmost care, for the JB Weld was applied on the plastic surrounding the lens, and if too much was put on it would cover the lens when the acrylic was applied. Next, the cameras were placed in a silicone mold and cast in epoxy. The mold was made using a 3D printed part slightly bigger than the cameras, which gave the cameras a thin layer of epoxy around their entireties.

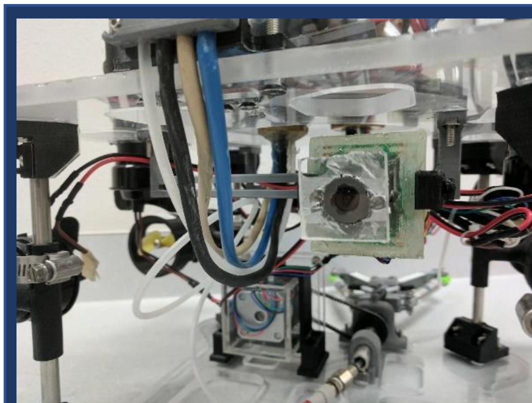

Figure 2.6 Waterproofed, and mounted camera

Claw

The claw is mainly constructed of 3D-printed parts, allowing for low cost customization, and was modeled using Autodesk Inventor. It is designed to be multifunctional and adaptable to different-shaped objects, and is specifically sized to pick up ¾" PVC. Silicone was added to the claw ends to give them a rubbery texture, which helps it keep hold of the various objects. It opens and closes via the action of two pneumatic single-acting linear actuators, which when pressurized, cause the claw to close. When depressurized, a spring returns the claw to its open position. The claw is used throughout the missions, collecting sediment samples or connecting and disconnecting power cables, as it is able to grasp various types of objects. All moving parts of the claw are labeled, in order to prevent accidents.

Figure 2.7 Claw when removed

Furthermore, the claw is also removable, and can continually rotate by use of a stepper motor, which is enclosed in a waterproof housing. The claw is able to continually rotate because there is a bearing around the claw shaft. Only a single hose is needed to feed the cylinders, and there is a rotating tube fitting that allows the pneumatic hose to continually rotate without being damaged. The bearing around the shaft is press fit in place and is inserted into a bearing holder on the frame. This bearing holder has a set screw that holds the claw in place. The pneumatic line that feeds the single acting cylinders travels through the shaft of the claw, which is a stainless-steel tube. With the addition of the continually rotating push-to-connect tube fitting on the pneumatic line where it exits the shaft, the entire claw can spin and be easily removed.

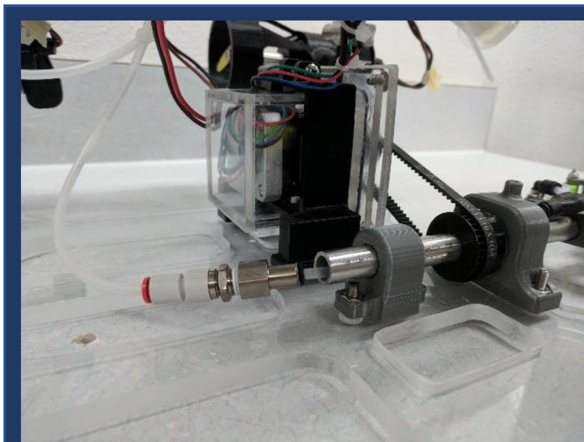

Figure 2.8 Stepper motor housing and mechanism enabling rotation

The stepper motor that drives the claw’s rotation does so by use of a belt and two pulleys. One pulley is attached to the shaft of the claw, and the other to the shaft of the stepper motor. The stepper motor is inside its own custom waterproof housing. This housing is made of acrylic and sealed using O-rings. A square profile O-ring seals the lid of the housing, and a x-profile O-ring seals the shaft. The stepper motor itself is screwed to the lid, with the head of the screws sealed in silicone on the outside to keep out water. This housing has been tested in depths up to 3 m and has proven waterproof. The housing is held to the frame by a 3D printed part, which is connected to the bottom plate via four screws. The plate has a slot 3 cm long for each of these screws, which allows the distance between the claw and the stepper motor to be adjusted. This makes it possible to adjust the tightness of the belt between the claw and the stepper motor.

Electronics Housing

Finnobot’s electronics housing has an outer diameter of 20.3 cm (8 in) and a height of 10 cm. It was custom designed and constructed by our team, and is made primarily of acrylic. Acrylic was chosen because it is lightweight, rigid, inexpensive, easy to machine, and clear, and because it forms strong glue joints and good seals. Being transparent allows for visual inspection of components and status lights within the housing as part of the prelaunch safety checklist and post-mission inspection.

The housing is made of a ⅛” thick cylinder, ⅜” thick lid, ¼” thick flange, and ⅜” thick bottom plate. The entire housing was first designed in Inventor, and once it was sufficiently modeled, the lid, flange, and plate were cut out using Autodesk HSM (Inventor CAM software) and a CNC router. The bottom plate and the flange were glued to the cylinder using #16 acrylic cement. These joints were strengthened by a bead of JB weld and a 3D printed ring. The lid is held onto the flange by eight screws, and a large ⅛” thick rubber gasket between the lid and flange ensures the housing stays watertight.

Figure 2.9 Electronics housing

We chose to make an electronics housing with a relatively large opening, as opposed to a longer one with a small opening, because it would allow for easier placement of electronics, and quicker access to said electronics. The wide opening, however, made it necessary to use a relatively thick lid and end plate, for these parts are put under heavy stress with depth. According to our depth calculations, the housing itself can safely survive a depth of 16 m; the seal, however, has only been tested to 4 m. Additionally, the lid contains a vacuum test plug for pre-mission seal testing, to verify housing integrity.

The housing has two bulkheads, one for tether entry, and the other for all the wires leaving the housing, including the wires for motors, cameras and the simulated Raman spectrometer. These bulkheads were custom made and use brass tank fittings, which have an inner diameter of about 2.1 cm and outer diameter of 2.6 cm. They have a built in O-ring groove and are held in the bottom plate of the housing with a nut, giving them the ability to form strong watertight seals and still be easily removable. The wires are sealed inside the bulkheads with West System two-part epoxy.

Control System

The primary component of our control system is an Xbox 360 controller, which allows us to operate all six of the thrusters. We chose this specific controller because it can produce analog values for both joysticks as well as the triggers, which allows for variable motor speed. We programmed the Xbox controller so that the left joystick operates the directional movement of the ROV; essentially the ROV goes in the direction that the joystick is pointing, thanks to the vectored thruster design. The right joystick on the controller allows for rotational (yaw) movement of Finnobot when pushed left or right. The two triggers on the controller are used for ascending and descending in the water. When the right trigger is pressed, the ROV ascends in the water. The opposite occurs for the left trigger. We also added two different speed settings for driving Finnobot, which makes it easier to make fine adjustments during tasks. By simply pressing a button on the controller, the software switches between the speeds.

Figure 2.10 Xbox 360 Controller

In addition to the Xbox controller, we added a Bluetooth keyboard as a second input method for operating the ROV. This allows the team to have both a pilot and a co-pilot for completing missions. The keyboard has been programmed to control claw rotation, claw opening and closing, and the simulated Raman spectrometer. Using the keyboard, the co-pilot can control the claw rotation both manually and automatically. For the opening and closing of valves, the automatic mode can be used, which makes the claw rotate three times. Having a co-pilot is very beneficial, as one person can focus on driving the ROV into position while the other can operate the claw functions.

We have also included a way to remotely reset the Arduino onboard the ROV, in case a malfunction occurs in the software. In the control box, there is a button that is connected to the reset pin on the Arduino via a conductor in the Ethernet cable. When this button is pressed, it connects the reset pin on the Arduino to ground, resetting both it and the code running on it.

Control Box

One of the major improvements our team wanted to make based on our previous year involved the control system and transportation of Finnobot. Last year we had a very simple control station for operating the pneumatic claw, and a controller plugged into our laptop. While this setup worked, it was very inefficient because every team member had to end up carrying part of what was needed to set up. This caused the overall setup and deployment time to be compromised when doing missions. In order to resolve this issue, our team decided to design a control and transport system that would help to streamline deployment, simplify ROV transport, and provide a solid, easy to use control system.

Figure 2.11 Control Box

Figure 2.12 Control box with electronics mounting plate closed

The main component of our topside control box is a large study case that was donated by our local aquarium. This case allowed us to engineer all the major components of the control system in a clean and organized manner. One of the most important attributes of our control box is that it acts as the location for all of our topside electronics. We decided that mounting the electronics into the lid of the box would be the best solution because it is separate from the main compartment, which is important for safety. To do this, we mounted all of the topside electronics onto an acrylic sheet, so that the wiring would be neat and easily accessed. Also included on the electronics mounting plate is the main shutoff switch for the ROV, which can be easily reached when completing missions. This acrylic sheet is mounted to the bottom of the lid via hinges, which allows us to open and close the electrical system for maintenance. The mounting plate is secured by two wing nuts at the top of the lid.

Another safety addition that is included with our control box is strain relief for the tether. We have engineered a method that allows for the tether to have strain relief, but also be removable. This is very important for transportation of Finnobot. The strain relief is accomplished individually for each of the components of the tether, which allows for stronger and safer strain relief. The tether can also be disconnected from the electronics plate, in order to be completely separated from the control box.

We have also mounted a surge protected power strip onto the inside of the case to provide AC power for components such as the video multiplexer and air compressor. The power strip has an external connector on the control box that can be connected to any AC power source via an extension cord. In addition to the AC power input, we added Anderson Powerpole connectors on the outside of the box which allows us to plug the control system into MATE power with one removable cable. The power from these connectors then leads to the electronics plate.

A few features have also been added for easy transport of Finnobot. Since the ROV was designed with motors that can be rotated inwards for transportation, the entire ROV fits easily into the main compartment of our box. This allows us enough room to wrap the removed tether and store it next to the ROV, along with any other items that will be needed for the missions, such as a contaminant buoy. We also added caster wheels onto one end of the control box, so that it rolls similarly to a suitcase, which is helpful for situations where only one person is available for transporting Finnobot.

Electronics

Topside Electronics

*See Appendix B for SID showing electrical connections

Figure 2.13 Raspberry Pi 3 Model B mini computer

Our electronics system revolves primarily around a Raspberry Pi 3 on the surface, and an Arduino Due in the ROV. The reason for using a Raspberry Pi as opposed to a laptop was to save space, and to provide a direct serial communication output. The Raspberry Pi acts as a mini computer that allows us to run our control software. The Raspberry Pi also has a set of GPIO (General Purpose Input and Output) pins that allow us to operate a relay, or any other electronic device if necessary. Another benefit to using this mini computer is that it can run off MATE power, which is important for maintaining one common ground for all the electronic systems.

One issue that arises when using the Raspberry Pi for serial communication to the Arduino is that it uses the basic TTL protocol, which can only send signals a limited distance. To resolve this issue, we decided to convert the TTL signal into a more standard RS232 protocol signal, which is capable of spanning distances of several hundred feet. This is done using a converter directly after the serial signal comes out of the Raspberry Pi. Once the RS232 signal reaches the ROV, it must be converted back to TTL, using another converter, so that the Arduino Due can understand the signal.

On the electronics mounting plate in the control box, we have included a DC power filter directly after the main shutoff switch. This is a very crucial component of the electronics system because it reduces electrostatic noise in the power that can be harmful to sensitive electronics like the Raspberry Pi. There is also a 5V DC-DC converter after the power filter, that provides power to the Raspberry Pi. We chose a DC-DC converter, instead of a simple voltage regulator, due to the increase in efficiency. Also connected to the Raspberry Pi is a relay which operates a solenoid valve for opening and closing the claw.

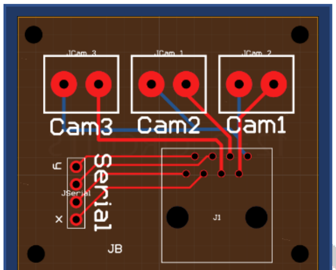

Figure 2.14 Ethernet breakout board design

Another important component on the topside electronics system is a custom Ethernet breakout board the we have developed (Figure 2.14). We designed this PCB using 123d Circuits and had it manufactured by OSH Park. Developing our own breakout board allowed us to customize the design to fit our specific needs. On the board is a connector for plugging in the Ethernet cable coming from the tether, three sets of screw terminals for plugging in video lines, and a male 4-pin header that allows us to connect the serial communication lines. The three video signals coming out of the breakout board, and a video signal coming out of the Raspberry Pi, all get fed into a video multiplexer that combines all the signals into one video signal output. This is then converted to VGA and sent to the monitor for the pilot.

ROV Electronics

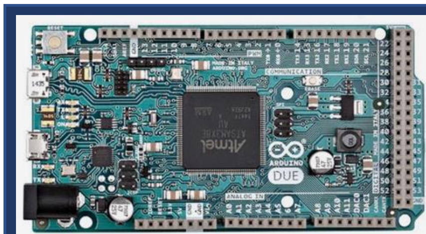
Figure 2.15 Arduino Due Microcontroller

We chose to use an Arduino Due as the main microcontroller onboard Finnobot for a variety of reasons. Our team has used Arduinos in the past, so we had a fair amount of knowledge about them already, which influenced our decision to continue using them. The Arduino Due has an operating voltage of 3.3V instead of 5V which is common for many of the other Arduino versions. This was important because the Raspberry Pi runs on 3.3V, therefore we don't need to add a logic level converter. Additionally, an Arduino Due is a much larger board compared with the standard Uno, which is helpful because of the increase in inputs and outputs on the board. Another benefit to using this Arduino is that the processor runs at 84 MHz, as opposed to the much slower, 16 MHz of an Arduino Uno. This faster processor allows us to interpret the incoming serial data much quicker, and thus, not cause a delay for the pilot.

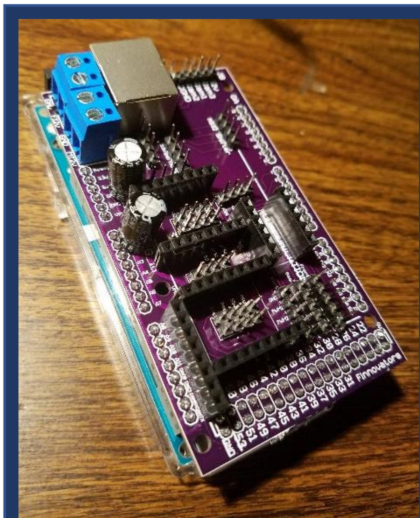

Figure 2.16 Custom shield attached to Arduino Due

Last year we had an issue where all the wiring and electronics in the housing became very messy and difficult to troubleshoot if an issue arose, especially since many of the wires were soldered into place. This year we resolved this issue by developing our own custom Arduino shield (Figure 2.16), once again designed using 123d Circuits, and manufactured by OSH Park. A shield is normally a purchased add-on that provides additional functionality to the Arduino, for example an Ethernet shield would allow the Arduino to be connected to a network. Our custom shield is primarily used for organization inside the pressure housing. We added headers that were the appropriate size for almost all of the various components in the pressure housing. For example, there are three 5-pin headers that allow us to easily run a ribbon cable between the Arduino and the motor controllers, instead of 15 individual wires. Also included on this shield is the connector for the Ethernet coming from the topside control box, which is similar to the breakout board previously mentioned, except it combines the inputs into the one cable, instead of splitting them out. Additionally, we mounted a DRV8825 stepper motor driver onto the shield, along with the needed capacitors for smoothing; this driver is used to power the stepper motor that rotates the claw. There is also a header that takes incoming power and sends it to a 9V DC-DC converter used for powering the Arduino Due.

Similar to the topside electronics, we added a power filter inside the ROV. This power filter is arguably more important, due to the close proximity to the DC motors, which generate noise when operating. The power filter separates the sensitive electronics from the dirty power on the main tether line, and from the motors. This year we decided to change the motor controllers that we had used previously, with newer ones that support more current, and true PWM signal inputs. We are using three 10A 5-25V Dual Channel motor drivers by Cytron (Figure 2.17), which have proved to be very reliable and user-friendly motor controllers. They control the thrusters individually using a PWM signal for variable speed, and a direction signal for motor direction. In addition to the motor controllers, we also have a relay inside the housing for operating the simulated Raman spectrometer. To simulate the Raman spectrometer, we are using a 12V LED light (Figure 2.18). Originally this light was designed as a headlight for a drone, and thus it was quite bright and easy to waterproof using epoxy. In order to keep the inside of the housing as organized as possible, we didn’t want to add large terminal blocks for splitting the DC power from the tether. Instead we decided to use ring terminals on the ends of all the 12VDC wiring, which allowed us to simply run a bolt through the terminals and secure it with a nut to complete the connection, which were then covered for safety.

Figure 2.17 Dual motor controller

Figure 2.18 Raman Spectrometer

Tether

The tether is another area we wanted to improve upon from last year. Previously, our tether was quite large, difficult to manage, and stiff enough that it affected the ROV in the water. Therefore, it was important for us to create a smaller, more flexible tether. Several modifications were made, such as using an Ethernet wire for both communication and camera signals, using highly flexible power wire, and only using one small pneumatic line for the claw.

The tether contains one Category 6 Ethernet cable, which is used more in terms of an eight-conductor wire than the standard Ethernet protocol. Four of the lines are used for cameras, three for communication, and one as an Arduino reset. From our experience last year, we learned that voltage loss is a problem if the power wire is too small. Therefore, we are using a 2/10 AWG high strand EPDM rubber-insulated DC power line, which is both extremely flexible, and has a voltage loss of only 0.7 volts over the length of our tether. The pneumatic line we chose is a 5/32 OD pneumatic tube that is small enough to be flexible, yet still plenty large for efficient claw operation.

The overall length for the tether is approximately 16 m from Finnobot to the topside control system, which is long enough for any pool operating environment. Both ends of the removable tether have well engineered strain relief for safety. When Finnobot is weighed and measured, the tether wraps nicely around the structure to reduce size.

Ballast System

Using Autodesk Inventor, it was determined that Finnobot would have a displacement of approximately 10,000 cm^3. By using Archimedes Principle, we determined that given this displacement, and the density of water at 1g/cm^3, Finnobot would have to be 10 kg in order to be neutrally buoyant. It ended up having a mass of 10.6 kg, so some flotation had to be added to keep it neutrally buoyant. At around 3,300 cm^3 the acrylic electronics housing is Finnobot's single largest displacement component, and serves as the primary buoyancy device. In order to keep an ROV level and upright underwater, the center of buoyancy must be directly over the center of mass. By locating the electronics housing on the top of Finnobot, and everything else below it, we have assured the center of buoyancy is above the center of mass. However, because the claw and stepper motor, two of the heavier parts, are located towards the front of Finnobot, the center of mass was in front of the center of buoyancy, which would have caused the front of the ROV to lean down. This issue was realized during the design process, but it was difficult to determine exactly how far forward the electronics housing should be placed to counteract this. The solution we reached was to have slots on the top plate that would allow the electronics housing to be moved forwards and backwards (Figure 2.19). This gives us the ability to easily adjust the center of buoyancy, and position it directly over the center of mass, assuring that the ROV stays level underwater.

Figure 2.19 Adjustable electronics housing mounting system

Originality

Because of both budget restrictions and a desire to innovate, Finnobot has a multitude of custom components that were designed and constructed in-house. These include the electronics and stepper housings, the claw, the control box, the Arduino Due shield, the cameras, bulkhead connectors, and much more. Underwater housings are quite expensive - a Blue Robotics' 8" Series Watertight Enclosure, for example, would have cost nearly $400. By making our own we saved over $300 and gained experience working with acrylic and seals. Additionally, our stepper motor housing cost us next to nothing to make, for we used left over acrylic and a couple O-rings (maybe $15), and saved us tremendously compared to buying a pre-waterproofed motor. Another major source of saving came from our bulkheads. We got a quote from *MacArtney* for the underwater connectors we would need, and even at a discounted price they would have cost $800. By making our own for only around $20, we lost some abilities, for the bulkheads can only be removed if all internal connections are disconnected, but we saved a tremendous amount of money, and learned how to seal wires in epoxy. The cameras only cost $13 a piece and were custom waterproofed, a process that only cost as much as the epoxy used to seal them. Waterproofing them also gave us additional skills in casting with both epoxy and silicone.

Parts such as our claw, control box, and Arduino Due shield don't have any very similar commercial counterpart, but they all display a high level of workmanship and were made budget friendly and with great precision. Additionally, many parts were 3D printed, such as a majority of the claw, the motor shrouds and the camera mounts, allowing for low cost customization and easy replaceability. 3D printing also made prototyping possible, which helped us fine tune our design for little cost. Additionally, since Finnobot was built out of nearly all custom parts by our team, we know it very well, so we can make alterations as needed and know how to fix any issues that may arise.

Safety

Shop Safety

Safety is an essential part of any process concerning construction, electronics, or mechanics, and was therefore influential in the building and operation of this ROV. Throughout the process, team members ensured that the following safety precautions were taken:

- Safety glasses worn
- Workspace cleared of obstructions
- Supervision by mentors when necessary
- First aid kit and fire extinguisher on hand
- Pressure housing tested before each use to avoid water leakage
- Ventilation for soldering
- Electronics appliances unplugged when not in use

Vehicle Safety Features

Safety features and practices are not only designed to protect personnel but also to prevent irreparable damage to the ROV. Finnobot has all of the MATE Center's required safety features including: caution labels for moving parts, strain relief on the tether as well as all other cables, a 25 amp fuse within 30 cm of the power supply, and shrouds around each propeller. The proper value for the fuse was determined by summing the amperages of all systems (measured individually with an ammeter), then confirming the ROV's total amp draw. In addition to the safety features required by MATE, we have implemented some of our own, including a main power shutoff switch, surface voltage and amperage meters, and a vacuum depressurization system to test for leaks in the electronics housings prior to launching the ROV. Additionally, the clear acrylic housing allows for visual inspection of the electronics and various waterproofing techniques ensure all electronics remain dry, protecting them from short circuits. Below is a safety checklist that lists the process our team undergoes before using or interacting with the ROV.

Safety Checklist

Pre-Power

- ❑ Safety glasses on
- ❑ Area clear/safe (remove tripping hazards, excess items, etc.)
- ❑ Ensure shut-off switch is off
- ❑ Tether prepared for launch
- ❑ Tether connected to control panel
- ❑ Pressure housing sealed
- ❑ Thrusters free from obstructions
- ❑ Verify air supply regulation
- ❑ Ensure air supply is connected to pneumatic system
- ❑ Power source connected to ROV
- ❑ Buoy prepared

Power-Up

- ❑ Power on
- ❑ Ensure Raspberry Pi is running
- ❑ Start program
- ❑ Monitor on
- ❑ Verify video feeds
- ❑ Air compressor on 12
- ❑ Update trigger values
- ❑ Test thrusters with controller
- ❑ Test claw operation

Launch

- ❑ Place ROV in water
- ❑ Deploy collection basket

In Water

- ❑ Check for water leaks
- ❑ If bubbles are present
    - ❑ Remove ROV from water
    - ❑ Investigate source of bubbles
- ❑ Otherwise
    - ❑ Engage thrusters and begin mission

ROV Retrieval

- ❑ Surface ROV
- ❑ Ensure motors are stopped
- ❑ Remove ROV from water
- ❑ Remove basket from water

Power-Down

- ❑ Shutdown Raspberry Pi
- ❑ Turn off main power
- ❑ Turn off air compressor
- ❑ Turn off monitor
- ❑ Unplug tether from all connection points

Testing and Troubleshooting

Testing was a key element of the ROV building process, and was instrumental in creating the final product. Such testing took place at multiple steps of the ROV construction, starting with the control system coding. After deciding to use TTL, we found that it would not travel the needed distance over the tether, indicating that we needed a method for carrying the serial communication signal farther. We decided to convert the TTL to RS232 and back again because RS232 can travel much further, and span the full distance from the robot to the topside control box. This process proved itself to be very challenging and required about five hours of troubleshooting before finally working, due to the lack of documentation for the converters we were using.

The software also required ample testing. When testing the code, we checked for proper interactions between the hardware and software, and would add one new component at a time so that we would know what specifically was causing problems. In the event that we did find an error, we would first attempt to fix the problem by making small changes to the way the component was wired. If this did not help, then we would look for potential solutions within the code. Once the system was giving us the desired results with the component, we would add another component. We continued until the software worked as we desired across all pieces of hardware. While testing the Arduino Due and the motor controllers with the newly written code we accidentally shorted our Arduino. This taught us to be more careful, and afterwards we made a dedicated motor testing wire that kept the motors a safe distance apart, and helped to clean up the whole testing process with motors.

We were also able to use our past experiences as methods of testing, and apply our gained knowledge to this year's project. We had troubles in the 2016 competition with our cameras leaking, and realized that we needed to come up with a reliable method for waterproofing. Our solution was to make a mold for epoxying the cameras, allowing them to be completely waterproofed over long periods of time. After testing the newly epoxied cameras in a pressure chamber, we found them to be waterproof in pressures equal to depths of 11 meters for extended periods of time.

Once an operational version of Finnobot was completed, it was tested in a dry run in which the vehicle was powered and bench tested in a controlled environment to ensure safety. The vehicle was then placed in a practice tank to adjust the buoyancy and test the waterproof housings. During this first stage of underwater testing, the ROV did not receive any power, which was good because the electronics housing proved to have a leak. Moving forward, we fixed this leak through a redesign of the housing that proved successful, and made some more minor alterations to buoyancy and the claw.

We then moved to the second stage of testing, which involved a powered pool test with the props. The electronics housing was vacuum tested before this and was proven watertight. During this series of tests, we examined the cameras, claw, housings, tether, and movement. The cameras proved to work over the 16 m of tether and were adjusted to have an adequate view of the claw, props, and surroundings. The

Figure 3.1 Finnovator's second pool test

claw proved very good at gripping objects but it didn't have enough torque at high RPM and therefore had trouble rotating, especially while spinning the valve in the Entertainment: Light and Water Show Maintenance mission. To mitigate this issue, we edited the code so that the stepper motor spun slower, and loosened the belt between it and the claw. Together these increased the motor's torque and prevented it from binding up. At this point we also tested voltage loss over the main power lines of the tether and tested how well the motors worked and how much current they drew under full load. We found that even with all six of the motors running at full thrust, the ROV was still well under the maximum power that the system can handle. Vertical movement at this point, however, was very slow. The cause of this was a lack of area for exhaust from the motor to flow, which resulted in the exhaust pushing the frame of the ROV down when we were trying to go up. To overcome this, we moved the vertical motors out from the frame, which involved a complete redesign of their attachment methods. Lastly, we took the ROV down to four meters at this point to ensure all the housings were water tight. No leaks were found even after extended periods at depth.

Project Management

Our team began meeting four months before the regional competition to plan the ROV. We spent an entire month making sketches and discussing potential ideas for all the components of the ROV. We familiarized ourselves with the manual and the tasks we needed to perform, and created an estimated budget to see how much money we would need to spend. A Google calendar was created to share all our other activities and to have a visual planner that showed everybody when and where we would be holding meetings. Our team also created Facebook and Skype group messages. These were valuable for times when we were individually working at home and had questions for our group. After our planning stage, we ordered all the parts we needed and began construction. Our construction phase consisted of a solid three months of work, with many failed tests (see Project Testing) that helped us improve our ROV. Our team met at least once a week in the first two months of building, and anywhere from 2-6 days a week after that until the international competition. We kept our meetings occurring regularly to ensure that all team members remained active and engaged in the building process, and we all worked together to ensure that everything was constructed in the best way possible.

Conclusion

Challenges

The biggest challenge that our team faced was finding time to all work together. Between sports, jobs, homework, musical lessons, and transportation problems, our team struggled to find time to all meet at the same time. However, we all modified our busy schedules to allow us time to collaborate as a team. Each of us additionally put considerable amounts of individual time into certain aspects of our ROV, which made our team meetings more productive. We all learned that when everybody makes little sacrifices, we all can all come together and work successfully.

Building our custom electronics housing proved to be one of the most difficult technical challenges we faced this year. Considering our lack of high precision CNC machines and any experience working with acrylic it actually went quite well, but it was nonetheless wrought with setbacks. For starters, we built our own CNC router this year based on the *Root 2 CNC*, and learned how to use both it and the software running it, which included *Repetier* and *Autodesk HSM*. Cutting acrylic proved to be particularly difficult, but once a method was developed we were able to cut out all the parts for the electronics housing as well as the plates for the frame. Gluing the acrylic for the housing went quite well, but an issue soon arose. We originally planned to use an O-ring groove between the flange and the lid, and had even cut a groove on the lid for it, but when we tightened the lid onto the flange we found that the flange was pried off the cylinder. This broke the glue joint between the cylinder and the flange and allowed water to leak in. This had two major causes: for one, the glue joint was weak, but also the screws were far enough out from the O-ring, and the O-ring groove was likely too shallow, which meant when the screws were tightened they had enough torque on the flange to break the joint. This was overcome by re-gluing the flange onto the cylinder with a stronger acrylic cement (#16 instead of #4), reinforcing the joints with a bead of JB Weld, and using a gasket that encompassed the entire flange so equal pressure is applied across it.

Future Improvements

The biggest improvement would be time management. As a team we are all extremely busy with school and extracurricular activities, which makes it challenging to get together and work as a team. We would like to improve this by creating a more comprehensive schedule and making sure to stick to the dates. Another improvement we would like to add to the ROV is additional sensors. With the addition of sensors such as a gyroscope and accelerometer, we would be able to make the ROV more stable in the water by adjusting the motor thrust based on the sensor values. We could also add a depth sensor so that it is easier to locate our position in the water. We would also like to improve the structural design of the ROV in order to reduce drag in all axes because we found that ascending and descending in the water was quite slow, especially when carrying a payload.

Individual Roles

The members of the Finnovators pictured (left to right: Natalie, Alex, Gatlin, Ryan, Damion, Jostan, Ruben, Sophie).

Natalie DeWitt, grade 12, Chief Executive Officer, 17 years old, wants to be a forensic profiler. Natalie helped to write the technical document and the poster, organized the team, and helped other members with individual tasks.

Alex Rash, grade 12, Chief Financial Officer, 18 years old, wants to be a software developer. Alex programmed the Pi to take commands and send them over serial. He also oversaw the budget and purchasing of materials.

Gatlin Andrews, grade 12, Chief Electrical Engineer, 18 years old, wants to be a software developer. Gatlin helped to make the tether as well as integrate all of the electrical components that were needed for the ROV. Gatlin also helped design the custom Arduino shield.

Ryan Russell, grade 12, Systems Engineer, 18 years old, wants to be a software developer. Ryan was the primary engineer for the topside control system.

Damion Chavez, grade 12, Chief Operations Officer, 17 years old, wants to be a marine biologist. Damion assisted with ROV construction.

Jostan Brown, grade 12, Chief Engineer, wants to be a mechanical engineer. Jostan designed all of the 3D printed and acrylic parts, built the structure and designed and built the claw and its pneumatic system.

Ruben Krueger, grade 12, Research and Development Officer, 18 years old, wants to be a mechanical engineer. Ruben wrote the press release, grants, and helped to write and edit the poster and the technical document.

Sophie Goodwin-Rice, grade 12, Marketing Officer, 18 years old, wants to be an international journalist or psychologist. Sophie wrote grants, and helped to write the poster and technical document.

Lessons Learned

We all learned a variety of valuable lessons throughout the entire process of the competition. As a team, we learned how to communicate effectively, and work off each other's' strengths. One of the most valuable lessons we learned is that things will always take longer than planned. Throughout the process of building the ROV, we found that tasks we thought would be quick and simple would turn into several hour-long projects. We also learned that thorough testing is very important for every stage of the build. Testing allows us to discover and fix issues that we would not have discovered otherwise. Lastly, during the building of the ROV, many team members learned new skills, including soldering and computer coding.

Reflections

Natalie: Joining the Newport High School Robotics Team was my first exposure to hands on engineering. I have learned so much about mechanics and how much work actually goes into designing an ROV, and it has peaked my interest in continuing my education in mathematics and engineering. I have learned the basics of AutoCAD and how to 3D print objects. I also helped to design our structure and used math from previous math courses to determine the different sizes of ROV parts. I learned about creating a company, and as the CEO of our company, I learned how to represent my team during simulated business situations. I was exposed to the world of engineering in a very positive way, and I am now more excited than ever.

Ryan: Hi, I am Ryan. I am a senior at Newport High School. Last year was my first year and I had a blast. This year I wanted to build a robot that would beat out last year's robot. The robotics club has taught me so much about the mechanics of an ROV and how they work. Wiring everything was the hardest part. I liked learning the electrical part of the ROV. Last year I learned how to use AutoCAD and 3D print objects, this year I learned about the electrical systems of the ROV. My plan is to go to Oregon State University and study in their engineering program, specifically computer science. I also plan on joining the robotics team at OSU. I was a major part of building the control box. Once Gatlin and I finished the control box we started to help finish the ROV. We finished and then we started testing it in the pool. It was a very exciting year!

Alex: I have always thought it would be cool to work in the fields of engineering and computer science. The last two years of robotics have been a lot of fun and I have learned a lot. This year I worked to develop the python code that is used by a Raspberry Pi to help control our ROV. I also learned about serial communication between devices in both the TTL and RS232 protocols. Overall the process was comparable to solving a really big, complex puzzle. Though at times it was frustrating at times, I think that as a whole it was a fun, positive experience.

Gatlin: First, I would like to thank each and every person who has devoted their time and energy to making this journey possible. I can, without a doubt, say that joining the Newport High School Robotics Team, has easily been the best decision I have made towards advancing my future. The MATE ROV competition has given me the opportunity to further expand upon my passion for technology, and has given me motivation to strive for greatness. Being a part of the Finnovators team for the past two years has been an extraordinary experience, both technically and socially. Through robotics, I have been able to gain hands on experience and knowledge in electronics, programming, mechanical design, and ROVs, none of which would have been possible otherwise. I am very thankful to have been a part of this amazing opportunity.

Ruben: I have, for a quite a while now, been interested in becoming an engineer. However, it is difficult to find opportunities to engage in the engineering profession, save for internships.
This year was my first year in robotics and it has been great; I have learned so much about coding, electronics, and building machines. I also have gained close friendships with my team members.

Jostan: I joined robotics last year because I'd always been passionate about electronics, engineering and mechanical projects. Through robotics I have faced many difficult problems and have had fun finding new and creative ways of overcoming them. Over the past two years I have become quite skilled at using Autodesk Inventor, operating 3D printers, soldering and using a CNC router and have become acquainted with programming, designing PCBs and many other exciting skills. Being able to practice these engineering skills on a practical level has been exciting and taught me many new things. Joining robotics was without doubt the best decision I made in high school, and I am very thankful to all who have helped make it possible.

Sophie: Throughout my first three years of high school, robotics seemed like a distant world, mainly because my interests primarily lay outside of STEM fields, and I wasn't sure how to go about exploring those fields without already having a vast knowledge of mechanics and engineering. However, when presented with the opportunity to join the Finnovators this year, I quickly found that the experience was much more interesting and exciting than daunting. As a writer, I have gained tremendous knowledge about technical writing (with which I had very little experience), and about the structure and roles of a company. As a student, I have learned all sorts of things I never thought I would have a reason to understand, from all aspects of the ROV design and building process. Most importantly, I've started to realize just how much STEM is linked to the rest of the world, and how much technological advancements can contribute to overall global advancements.

Damion: I am a senior at Newport high school. This is my first year being part of the robotics club. I joined because of my interest in engineering and marine technology. I figured that joining a team that will be assembling an ROV would be a perfect opportunity to pursue my interest. Shortly after joining the team I realized I don't have the adequate knowledge to really make a huge difference in the club. But that gave more motivation than ever to learn everything I could to help. Not only that, but the robotics club has helped me learn many great attributes that will be useful later in my life, such as soldering - before the club I didn't even know what that was. Now, I would call myself decent at it. It was things like this that made me regret not joining the team earlier. Joining this club has given me a nice insight of what's to come, and prepared me to take the next step in life after school.

Acknowledgements

We would like to thank the MATE center, Fred Meyer, Sexton Corporation, Georgia Pacific, Lincoln County, and Figaro's Pizza, for their financial sponsorship. We express gratitude to our mentors Liz Fox, Alex Turpin, Ben Capshaw, Corey Gillen, Abby Mason, and Jordan Colmenero for the guidance and technical knowledge that they provided. We are greatly appreciative of Newport High School Robotics, who provided us with funds, building supplies, and food during meetings. We are also deeply indebted to our parents (Sharon Nieukirk, Ted DeWitt, Zahn and Jamie Russell, Mark and Linda Andrews, Sean Rash, Jennifer Wrazen, Anna and Cameron Brown, Marvin and Nadine Krueger, Jim Rice, Cait Goodwin, Anja and Mark Chavez) for their moral support. Lastly, we would like to thank Oregon Stem Hub and AUVSI Cascade Chapter for their organization of our regional competition.

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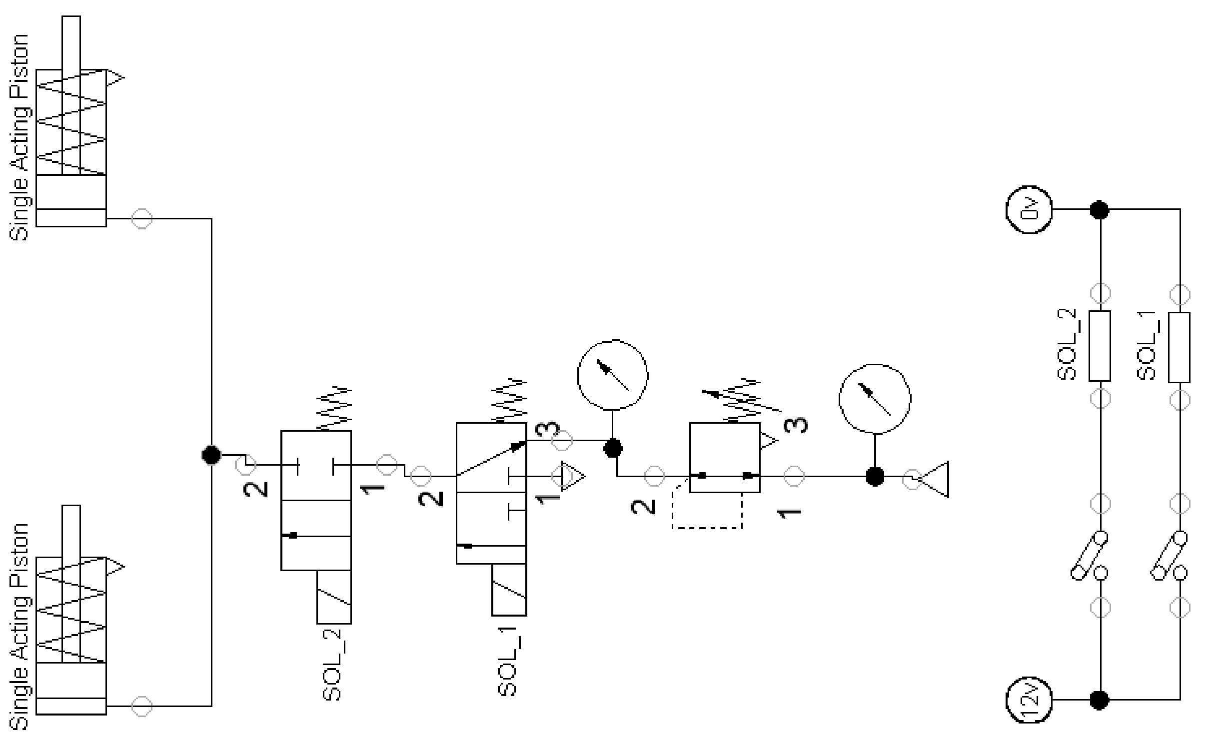
Appendices

Appendix A (Pneumatic SID)



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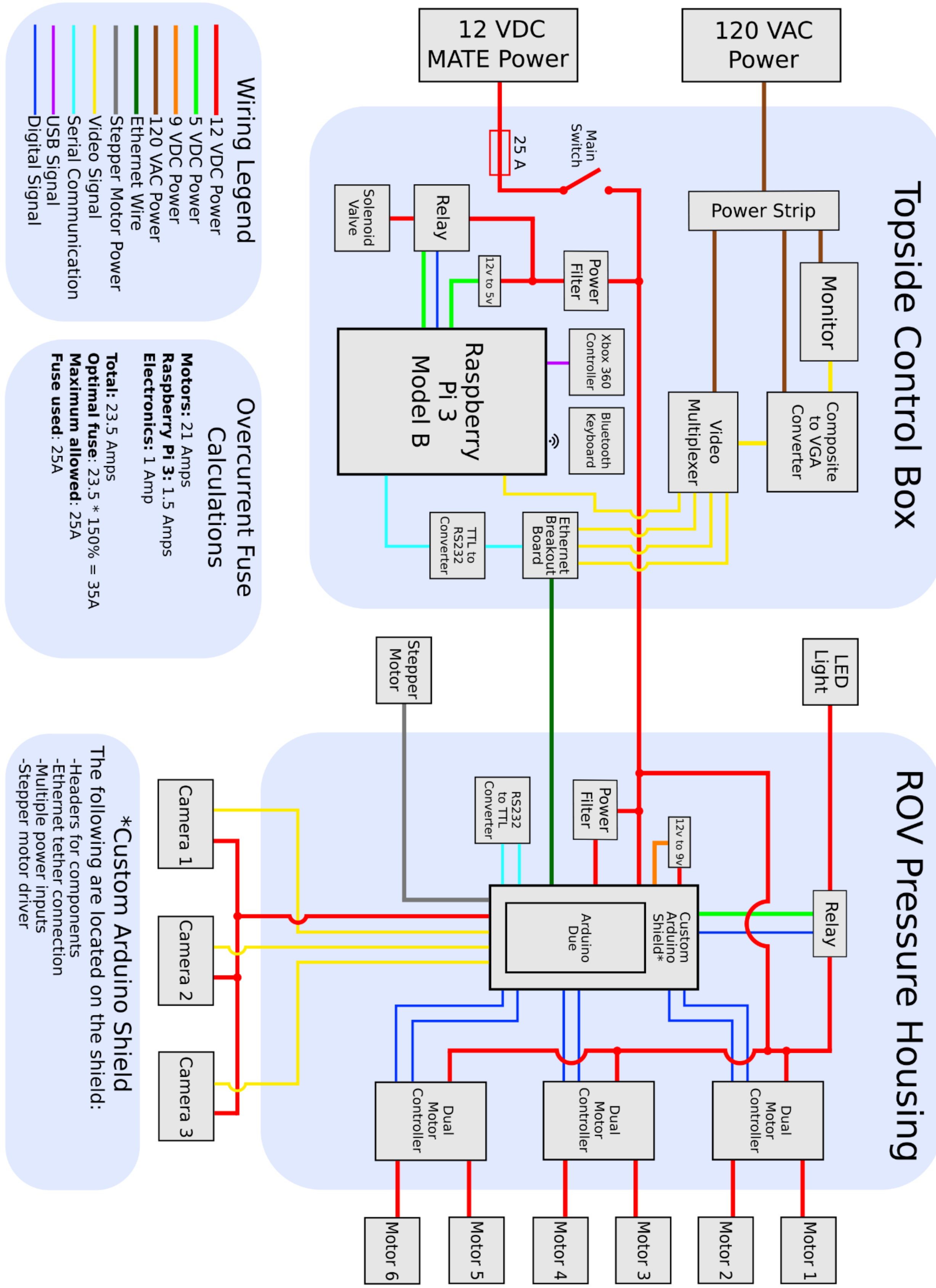

Appendix C (Software Flow Diagram)