2021 MATE Technical Documentation Ranger

Community Team
Pearl River, NY 10965
USA

TopSpin 3.0
Ping Engineering's 2021 Remotely Operated Vehicle (ROV)

Ping Engineering Team Members (left to right back row, front row):
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All members returning for a **THIRD YEAR** to participate in MATE Remotely Operated Vehicle (ROV) Competition.
Team Mentors: John Balison & Eileen Kennedy (not pictured)

Figure 1: TopSpin 3.0

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Figure 2: TopSpin 3.0

Abstract

Ping Engineering is ready to serve the global community by addressing the problems of plastics in our oceans, the impact of climate change on coral reefs, and the consequences of poor environmental practices. We have studied the core of these problems and are confident that we can offer solutions for remediation with our evolved technology, newly-designed hardware, and advanced software, while also taking environmental, social, and governance (ESG) factors into account.

Ping Engineering is thrilled to introduce our new remotely operated vehicle (ROV): TopSpin 3.0. This exceptional machine has been designed and constructed by our team of five engineers, incorporating a variety of mission tools in order to improve the conditions of our waterways, leaving us well-equipped to remove floating debris from the surface, determine the health of a coral colony, and deploy a secondary device to collect a sediment sample for research purposes. As a result, we hope to facilitate a shift to more environmentally-friendly practices among various industries to improve the health of the world's waterways.

TopSpin 3.0 utilizes new designs and components, such as 3D-printed grippers integrated with the legs of the ROV, while also reusing and renovating past designs, such as the aluminum frame. This combination of old and new features on our ROV creates unique and efficient solutions that can change the global and maritime community for the better.

Schedule/Project Management

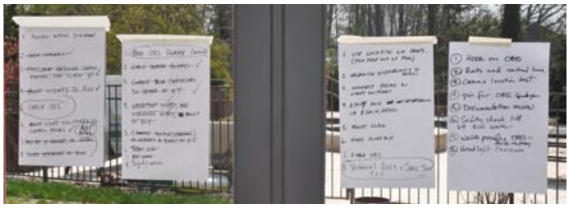


Figure 3: Meeting Agenda

Ping Engineering prides itself on delivering on-time, quality products. Due to the unforeseen circumstances surrounding COVID-19, we decided that a major emphasis should be put on scheduling. Our first couple meetings this year were conceptually-based, discussing how the ROV should work, what mission tools to use, and laying out a schedule for the rest of the year. After meetings dedicated to understanding the missions themselves, we decided that efficiency and simplicity were the main things we wanted to highlight. We set a calendar and milestones to encourage us to push through and stay on schedule. You can see our Gantt chart in the appendix.

After our first meetings, we divided into our areas of expertise and began work on the vehicle. Each person was given tasks for the meeting, and helping others was strongly encouraged. Even though the actual work was divided, we had biweekly check-ins from the whole team, as a recap to discuss where people were on their tasks/projects, and to explain what they were working on, how and if it worked. These recaps helped us better understand the tools and projects worked on by our peers, and helped us understand the machine as a whole. Whenever we were not in meetings, we communicated primarily through a group chat or via Google docs.

Not every meeting was solely working on the machine, however. Throughout the year, the beginnings of some meetings were dedicated to professional development. This development was the training and learning of specific conceptual scientific problems, mainly physics. In addition to the actual topic, these lessons taught problem solving, teamwork, and focus. These lessons taught us a better understanding of the machine, and were then applied to the ROV.

Design Rationale

Ping Engineering set out to design an ROV that is fast, efficient, and reliable. We also recognized the need for mission-specific tooling, and sought to develop custom solutions to successfully complete the various tasks.

Two major points of emphasis that influenced our design of the machine were:

1. Efficiency: There are a variety of tasks that must be completed in a very limited amount of time. TopSpin 3.0 needs to have the ability to move quickly and accurately while having excellent visibility so it can be piloted directly to the various targets, and have the ability to accomplish multiple tasks without surfacing or having the need to be fitted with attachments.

2. Simplicity: ROVs are by nature very complex machines. In order to maximize the machine's reliability, it's essential that all unnecessary complexity be eliminated, and all accessories and mission-specific tools should be designed to operate as simply as possible, and preferably unpowered. The grippers and any other powered tools should be powered by non-electric means whenever possible, avoiding the potential for waterproofing failures.

Frame

Loosely modeled after a jellyfish, TopSpin 3.0 is an elegant frameless design which uses an aluminium backplate, waterjet cut to our specifications, with all of its tools attached to the underside.

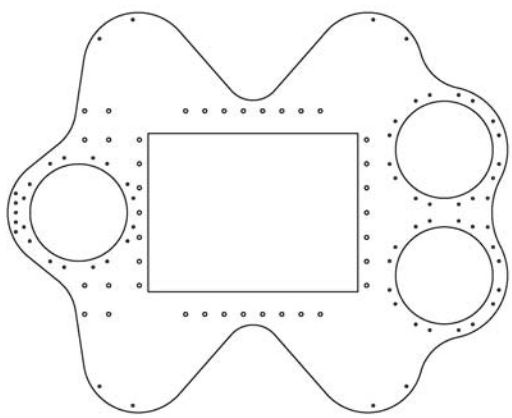


Figure 3: Backplate CAD model

We considered both aluminum, and high density polyethylene (HDPE) plastic for the backplate material. While HDPE has a clear edge in corrosion resistance, we selected aluminum because its strength to weight ratio is nearly triple that of HDPE, and it has excellent machinability and reasonable cost. In addition, the ability of the team to drill and tap threaded holes in the aluminum was an important factor, as our vision for the ROV required the backplate to function as the foundation with all of the tools connected to it.

During the planning phase, we decided to have the backplate fabricated with an abundance of holes for greater flexibility during the assembly process with the expectation that many holes would not be used.

Comparison of Backplate Materials		
	HDPE	**Aluminum (6061)**
Tensile Strength	38 MPa	290 MPa
Density	0.97 g/cm3	2.7 g/cm3
Strength to Weight Ratio	39.2	107.4
Corrosion Resistance	Excellent	Good

Buoyancy:

TopSpin 3.0 derives a portion of its buoyancy from its on-board electronics container, known as the Cranium. The Cranium is a plastic rectangular prism with a volume of approximately 3100 cm^3. With a negligible mass, the Cranium's displacement yields a buoyant force of about 3.1 kgf (30.4 N). The remainder of the ROV is negatively buoyant, so additional buoyancy was added to neutralize this. We mixed and created our own syntactic foam floatation to achieve this.

To select our supplemental buoyancy material, we looked at commercially available ROV's and deepwater exploration vehicles, and identified the industry standard types of buoyancy. We found two dominant materials: polyurethane foam, and syntactic foam. We also evaluated closed cell foam, a material that we have substantial experience with.

Comparison of Buoyancy Materials					
	Density	**Buoyant Force**	**Cost**	**Qualities**	**Design**
Closed Cell Foam	35 kg/m3	965 kg/m3	$	-Poor Durability -Absorbs Water	-Aesthetically unappealing
Syntactic Foam	500 kg/m3	500 kg/m3	$$$	-Easy to machine -Extremely durable -Incompressible	-Sandable and paintable
Polyurethane Foam	192 kg/m3	808 kg/m3	$$	-Durable -Compatible with many adhesives	-Easy to shape -Paintable

While closed cell foam was the cheapest and most readily available, we dismissed it from consideration due to its tendency to absorb water, and its fragile nature. We determined that either of the two remaining two candidates, syntactic foam and polyurethane foam, would serve the needs of our machine. Although syntactic foam is the most expensive to buy, we found that it was possible for us to manufacture it in-house, ultimately saving money. Therefore, we chose to use syntactic foam.

Syntactic foam is made up of hollow spheres bound together by a polymer. In our case, we mixed hollow glass microspheres and resin to create a mixture that was poured into 3D printed molds that reflected the shape of our backplate. The custom cast syntactic foam floatation fit perfectly on the top of the exposed aluminum.

Figure 4: A.Cacas/A.Han mix syntactic foam

Figure 5: A.Han sanding foam

Figure 6: A.Han painting foam

Propulsion System

TopSpin 3.0 utilizes seven T100 Blue Robotics thrusters, three vertical and four horizontal. The four horizontal thrusters are installed in a vector configuration where each thruster is rotated 30° from the forward direction of travel.

Our engineers considered both 30° and 45° vector configurations. We determined that a 45° configuration yielded the same thrust in all directions, while a 30° solution favored thrust in the forward/reverse direction. Our pilots felt that the ability to translate side to side was important, but that this type of movement was normally executed at very low speed, for example when better alignment of a tool was needed to complete a task. Most of the fast, long distance travel occured in the forward direction. Consequently, we selected the 30° vector configuration.

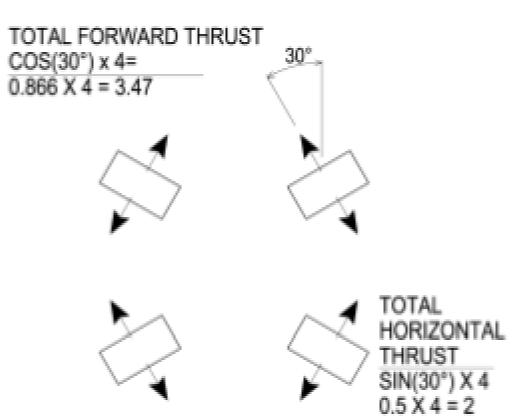


Figure 7: Illustration of Vector configuration with thrust calculation

The thrusters are controlled by two joysticks in the control box, with the main joystick controlling all horizontal movement - forward/backward, lateral movement, and YAW - and a second joystick controlling vertical movement.

TopSpin 3.0's thrusters are controlled by Electronic Speed Controllers (ESCs) from Blue Robotics. The ESCs are governed by a PWM signal, and at the maximum power consumption, the signal would range from 1100µs for full reverse to 1900µs for full forward, with 1500µs (+/-25µs) serving as deadband (neutral). The Blue Robotics thrusters are extremely powerful, with the ability to develop thrust exceeding 2.5kgf, but at the same time they also consume a lot of power. In fact, each thruster at maximum throttle can draw 12 amps of current. With a limit of 25 amps for the entire ROV, we were unable to fully utilize the power of each thruster. Therefore, power to the thrusters was budgeted through the software by limiting the signal to a range of 1300µs to 1700µs. This adjustment still provides a thrust of nearly 1kgf per thruster, while limiting the draw of each thruster to 2.5 amps.

Auto Level Pitch Control

With efficiency as one of the main priorities in mind, we have decided to incorporate an auto-levelling system. This idea came to us through previous failures, specifically last competition when one mission tool failed to release an object, leaving our vehicle permanently pitched. We soon realized this was a feature that would serve multiple purposes, especially whenever our grippers were in use. It works through an angle sensor mounted level in our Cranium, measuring pitch, and starting at zero degrees. Whenever the ROV pitch exceeds 5 degrees forward or backward, the vertical motors will respond with thrust to counter the pitch and return the ROV to level. The corrective thrust is proportional, so more thrust is applied if the ROV is significantly pitched, while fine corrections are applied when the machine is nearly level. This feature allows for extra precision during each of our missions, and keeps the machine stable throughout the entirety of the competition, no matter the circumstance.

On-board Electronic housing (the Brain)

Our electronics are housed on-board the ROV inside an IP68 rated Integra enclosure. This 20.3 x 15.2 x 10.2 cm polycarbonate box that we call the "Cranium" has a clear lid, making any potential issues with either water leaks or other electronics issues easily visible. The rectangular shape and hinged lid also make for very easy access to the electronics within the cranium, so if there is a problem it can easily be tended to. This is in contrast to many competing ROVs, which use a cylindrical housing that can be challenging to open and reseal, in addition to being inefficient with regard to laying out the electronics.

The electronics in the Cranium include a Pololu Mini-Maestro Servo Control module that is able to control 18 servos and/or ESCs, a hydraulic pump, a 3 port hydraulic valve module controlled by 3 servos, ESCs for the 7 T-100 thrusters, the angle sensor, and an Arduno Nano to communicate the angle sensor output to the control box vial serial communication..

Control Box

Our control box is a brightly colored yellow waterproof case. It is fitted with a Lexan panel on which the knobs and joysticks are mounted, and the panel lifts up like a hood for easy access to the wiring. The controls include 2 joysticks for thruster movement, a third joystick for the Grabby Gripper 3000, a knob potentiometer to control the on-board hydraulic pump, and an LCD that can display the pitch of the ROV, and hydraulic pump speed.


Figure 8: Control Box

Our three grippers are controlled by an auxiliary control box that was created this year by our engineers in an effort to comply with public health recommendations under Covid-19. Dubbed the "Social Distance Box", it is attached to the main control box by a 7 foot ethernet cable and enables the copilot to avoid standing directly beside the pilot. This box features four knobs: three of them each control one individual gripper, and the fourth knob potentiometer is a spare.

Lastly, as an essential safety component, there is a kill switch in the control box in the unlikely event that something goes wrong and the system needs to be shut down.

Power is supplied to the control box by a power supply via Anderson PowerPole connectors, and a 25 amp fuse serves as circuit protection. The tether power also uses Anderson PowerPoles, along with RJ45 plugs for ethernet.


Figure 9 Tether

Tether

TopSpin 3.0's 60 foot long tether was custom designed and built in-house by Ping Engineering technicians. Our tether is intentionally manufactured to be longer than other standard tethers, due to the fact that some missions may require a longer reach. The tether consists of two 12 gauge copper power wires, one cat 6 shielded ethernet cable, and one cable with a single shielded twisted pair, painstakingly threaded through a polyester sheath.

We know that the performance of the motors will diminish as the voltage falls, and while the T100 thrusters are rated to operate between 6 - 16 volts, the size of the power cables was based on our desire to limit voltage loss to 3 volts, resulting in a minimum thruster voltage of 9 volts.

Given that the resistance of 10 gauge copper wire is ~1.0 . /1000', our calculations showed that 10 gauge wire would have voltage loss of approximately 3V when drawing 25 amps. We employed these conductors in our tether during ROV testing and found the tether to be heavy and cumbersome, impeding maneuverability of the ROV. Seeking to reduce the size of the power conductors, we suspected that it would be rare for the ROV to regularly draw the maximum 25A current. We connected an ammeter to the main power cable to monitor the current draw while we performed typical tasks with the ROV. We found that the current never exceeded 14 amps during ordinary use. As a result of this investigation, we were comfortable downsizing the power conductors in the tether to 12 gauge, yielding a theoretical voltage drop of 2.7V at 14 amps.

Software and Communications

TopSpin 3.0 uses an Arduino Mega in its control box, with inputs from a litany of joysticks, switches and knob potentiometers. Communication with the ROV occurs via simple serial communication between the Pololu mini Maestro in the Cranium, which will be discussed shortly, and the Arduino Mega in the control box. In the past, we have tried to communicate using the I2C protocol, but the protocol does not function well over long distances, requiring the use of extenders. These extenders proved to be unreliable, and so we made the switch to a more simple way of communicating with our machine.

We use a Pololu Mini Maestro servo controller to control nearly all of TopSpin's functions. It is located on the ROV in the cranium and receives information from the Arduino Mega over the tether through the use of the tx pin on the Arduino. The Mimi Maestro has the ability to control up to 18 PWM devices, and it controls the seven T100 ESCs, three hydraulic valve servos, the hydraulic pump ESC, and the controller for the bilge pump motor that powers the GrabbyGripper 3000.

The program that runs on the Arduino consists generally of a single loop that constantly monitors the position of the various switches, sensors and potentiometers, and performs calculations and if/then operations that deliver instructions to the Maestro. The Maestro relays instructions to the various components that cause TopSpin 3.0 to come to life.

Cameras

TopSpin 3.0 includes four HD drone cameras positioned for maximum visibility. The four cameras are oriented as follows: forward facing, downward facing, rear "gripper cam", and rear facing for the sediment retrieving Grabber Grippy 3000.

We’ve identified and tested three different types of cameras: drone cameras, IP security cameras, and car back-up cameras. Our evaluation yielded four key findings: all of the cameras could provide decent visibility for the pilot; the drone cameras had a surprisingly good picture for their tiny size; the security cameras were very large but they had a very good picture; and the drone cameras drew **one-tenth the current** of back-up cameras.

Our evaluation steered toward the drone cameras. Unfortunately, such an amazing product has a hefty price tag. At ~$40 a camera, they cost more than double the other cameras we were considering. However, **we deemed power and space management of the utmost importance**, and therefore we saw these drone cameras as worthwhile investments for TopSpin 3.0.

Camera:	Estimated Cost:	Size:	Picture Quality:	Power Consumption (Watts) :
IP Camera	$31	Large	★★★★½	10
Car Backup	$20	Small	★★☆☆☆	18
Drone Camera	$40	Small	★★½☆☆	2

Learning from past waterproofing failures and following our simplicity strategy, our engineers used CAD to design and 3D print camera boxes which were completely filled with resin and surrounded the cameras. Previously we tried using lenses on the box as our solution to waterproofing the cameras, however water finds even the tiniest of holes and then becomes trapped, obscuring the view. Completely encapsulating the cameras with resin was a simpler design and left no opportunity for water to reach the cameras.

Figure 10: Drone camera, waterproofed in 3D printed box

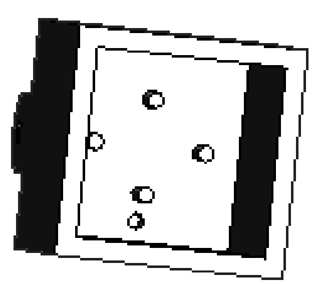


Figure 11: CAD model camera box

Ordinarily, video signals are transmitted over bulky coaxial cables. TopSpin 3.0 transmits video signals over twisted pairs using a device called a balun. These baluns allow us to transmit four video signals over a single shielded Cat 6 cable which provides for a more manageable tether. In the control box, the signals go from their respective balun into a multiplexer, which allows for all four of our cameras to be displayed on one screen.

Our camera system is operationally simple, but there are still many components and connections, and we struggled at times during the development and assembly process. Our problem solving skills were frequently put to use. For months, one of our channels did not work. This was difficult to troubleshoot, as there were so many variables to test, such as the individual camera, baluns, the Cat 6 wire, multiplexor, and numerous connections. We used the process of elimination by testing the parts on other channels until we determined that the balun on the control box was broken. The situation was remedied by replacing the balun.

Mission Tools

Hydraulic Gripper

There are a multitude of tasks that require a gripper when trying to clear pollution and maintain clean waterways. When fixing the problem of plastic pollution there are certain tasks such as disconnecting the power to a seabin, replacing the mesh catch bag on the seabin, and reconnecting the power along with many other tasks which all require the use of a gripper. Our company's engineers found that the use of one gripper to complete these tasks would be inefficient, so we created three custom grippers that can all be operated independently. We researched multiple grippers, such as servo powered grippers and commercially available grippers from Blue Robotics, however our own custom designed grippers were the clear choice due to their power, durability, and service underwater. Much of the design of our two front grippers was borrowed from the Blue Robotics gripper, but it has been tailored for the tasks necessary for keeping the ocean's waterways clear.

The three grippers are strategically placed with one on the back and two on the front to grab an array of objects. The two grippers placed on the front of the ROV are separated on each of the legs in order to steer clear of our upwards thrusters. One gripper is placed on the back side of the frame and is positioned higher up on the ROV than the other grippers. We designed it to be higher up for the seabin task because the seabin is close to the surface of the ocean, and when trying to retrieve the mesh catch bag and replace it we need our gripper to be positioned higher so that we can successfully grab the item without coming out of the water. Being able to easily design and place our grippers in optimal fashions for completing the tasks provided a clear advantage towards building our own grippers rather than purchasing commercially-made grippers.

The grippers are powered by durable, powerful, and precise double-acting hydraulic cylinders. Fluid pressure is generated by a pump in the cranium, and three servo-operated valves direct pressure to the cylinders.

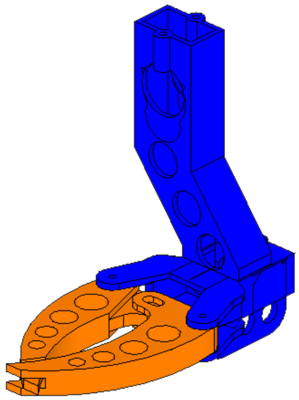


Figure 12: Gripper CAD model

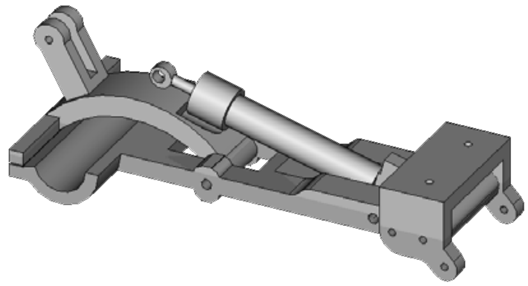


Figure 13: Back Gripper CAD model

Grabber Grippy 3000 (GG 3000)

In the Maintaining Healthy Waterways tasks, a sediment sample must be collected from a pipe. Our goal was to invent a tool that didn't involve a secondary, micro-rov. We designed the Grabber Grippy 3000 (GG 3000), a device that is loosely based on a 3D printer extruder. The GG 3000 is powered by a used bilge pump motor from our inventory, and it extrudes a plastic "snake" tipped with velcro into the pipe to "grab" the sample.

The extruded uses 2 wheels, one powered, one guider, that pinch the snake and push it out. Initially, we had the motor directly acting on the powered wheel. However, testing quickly showed that this was not enough torque to accomplish the task. We then tried adding 2 pulleys for extra torque, one 9 teeth and one 42 teeth, yet this still was not enough. We then researched methods of adding more torque, and discovered the jackshaft. The jackshaft allows us to transfer and then subsequently increase the amount of rotational force. This setup provides over 8 times more torque than our initial design.

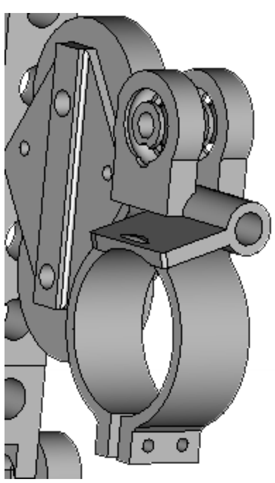


Figure 14: CAD drawing GG 3000

Figure 15: Grabber Grippy 3000

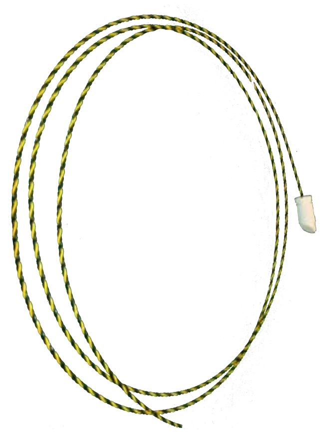


Figure 16: Snake for GG 3000

The Skimmer

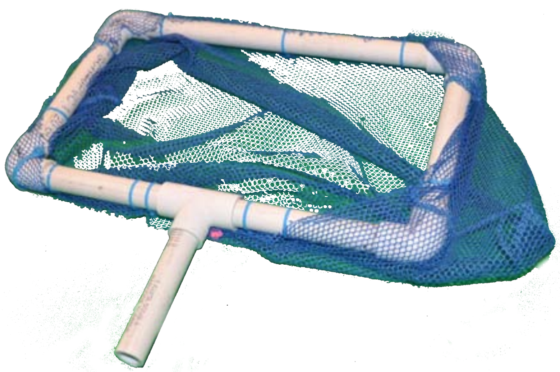


Figure 17: The Skimmer

Although cleaning fallen debris on the seabed is essential to cleaning waterways, it is also important to address floating debris. Thus, TopSpin 3.0 is now equipped with the Skimmer, which replicates the idea behind a pool skimmer. This low tech, simple tool was created with a PVC frame and attaching a cut-out mesh bag to it, which then acts as a net to collect the debris. The Skimmer is held in place with a pin going through its base and a plastic tube attached to TopSpin 3.0 itself, therefore placing the Skimmer at a higher elevation and allowing it to manage the floating debris effortlessly.

Build vs. Buy

Our decision to build and custom design TopSpin 3.0 was driven by our design rationale to create a unique, nimble and flexible machine. We enjoyed the process of sitting together and talking through possible solutions to complete the various tasks. We decided to build many of our parts, but where it wasn't feasible, we purchased some of the main components like the frame and cranium.

Figure 18: B.Kilkenny creating propellor shrouds in CAD

A major cost-saver for us was the use of our 3D printer. We realized the advantage of being able to custom-design our own tools after last year, and so we decided it was important to continue that. We had become significantly better at CAD and designing parts, and so it allowed for much faster work. Many tools and parts of our vehicle are custom 3D printed, including the grippers, the motor shrouds, the skimmer holder, along with smaller, more intricate things that complete our ROV. The use of the 3D printer allowed for cheaper, custom-made parts as opposed to specific, already produced parts. In our goal to make all of our mission tools, we also built the skimmer from PVC pipe and repurposed net. We decided that building the skimmer provided us with both an inexpensive and quality solution for clearing debris off of the surface of the water, leaving us no reason to purchase any commercial solutions. Furthermore, we decided to make our own integrated buoyancy this year as well.

In addition to the 3D printer, we machined some parts on a metal lathe. Some examples of machined parts include pins in the jackshaft, the legs of the ROV, and donuts to hold the legs. Again, the use of this machine allowed for important customization of the ROV, and allowed us to repurpose metal we already had, as opposed to purchasing custom products.

Although custom designed tools took more time to create, we believe it substantially improves the performance and overall function of the ROV, making it more appealing to our clients.

New vs. Used

With the success of our vehicle in the water last year, we decided to model TopSpin 3.0 loosely off of Topspin 2.0, last year's vehicle. Because of this, many parts were re-used, including the control box, the motors, motor shrouds, and many of the electronics; the performance of the motors, electronics, and other components that we experienced last year left us no reason to purchase any new parts to replace these existing components. We decided to buy a new frame that is modeled after last year’s frame, and we also purchased a more secure cranium box for our on-board electronic housing.

Not only were parts reused, but ideas as well. We decided to reuse ideas that worked well last year, including the concept of the propulsion system, the cranium, and the control box. After brainstorming what we wanted to keep, this allowed us to brainstorm the new ideas and new tools we would incorporate into our ROV, including the addition of more grippers and the rearrangement of motors.

In keeping with this year’s RFP, we re-used as much of our inventory as we could. Just around half of the machine was reused, with the other half new. Thanks to all of this, we were able to stay just under budget.

Safety

Company Safety Philosophy

Our company considers safety to be of utmost importance, which aligns with MATE priorities. We want everyone to have the experience of building an ROV, but safety is still an extremely important priority. It was important to prevent any possible accidents, as we did not want anyone to go to the Emergency Room. When working with power tools, we wore safety glasses, and when working with resin, we wore gloves to protect our skin. In addition, with the onset of the COVID-19 pandemic, we remained socially-distanced whenever possible and wore masks whenever social-distancing was not feasible.

Vehicle Safety Features

Socially-Distanced Copilot Function: One innovation we created this year to account for the COVID-19 pandemic is a socially-distanced copilot feature connected through our main control box. We essentially purchased a small and inexpensive plastic box in which we drilled holes into so that we could attach knob potentiometers. This copilot feature is able to connect to the main control box through an eight foot long Ethernet cable, and thus allows the main pilot, who controls the propellers of the ROV, and the copilot, who controls the grippers and all other specialized mission tools, to stand six feet apart while controlling the vehicle.

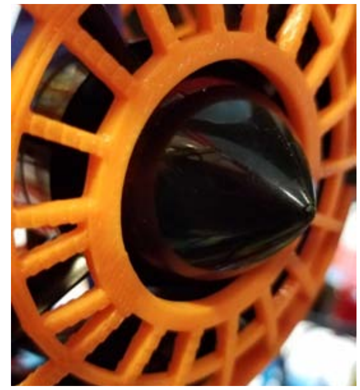


Figure 19: Orange shroud

Propeller Shrouds: We installed 3D printed propeller shrouds in safety orange so no one will get hurt while the motors are running. The shrouds are rated IP2 (ingress protection 2), indicating protection for finger sized objects, 12.5mm or larger in diameter.

Other Safety Features: TopSpin 3.0 also includes a kill switch and 25 amp fuse in case of emergency and to prevent an electrical overload. The tether includes a strain relief, to prevent any damage to the wires if pulled too fast and all edges of TopSpin 3.0 are rounded and dull to prevent any cuts or injuries due to sharp edges.

Finally, many of our mission tools are 3D printed with brightly colored orange filament, so that they are noticeable and notify people of moving parts.

Safety and Process Checklist

Workshop Checklist:

- ❏ Safety glasses are on while operating power tools
- ❏ Mentor supervision is present
- ❏ Gloves are worn while using resin
- ❏ Enough room is available while using the soldering iron
- ❏ Closed toe shoes are worn while in the workshop
- ❏ The ROV is not powered on while it is being worked on

Poolside Checklist (Pre-Submersion):

- ❏ Closed toed shoes are being worn
- ❏ The 25 amp fuse is in place
- ❏ There are no openings in the ROV
- ❏ Everything is properly plugged in
- ❏ Everything is off before putting the ROV in water
- ❏ Moving parts provide no risk of harm
- ❏ Tether is coiled neatly and all tripping hazards are accounted for
- ❏ Mentor supervision is present

- ❑ Everyone is ready

Critical Analysis

Prototyping

Some of our team members have become adept at CAD and drawing objects in 3 dimensions. Whenever possible, we attempted to prototype assemblies digitally, instead of 3D printing an object, tweaking it, then printing it again. We also made use of the internet, where we found that many "makers" are happy to share their ideas and experiences. In fact, we learned on one maker website that the plastic BBs made for airsoft rifles are a perfect 6mm sphere, and that they make excellent ball bearings for 3D printed bearing assemblies. We used a .stl file that was shared online by an anonymous user and upon printing it we used it as a prototype for our Grabber Grippy 3000 jackshaft bearing.

Testing and Troubleshooting

Unshielded Cat 5 vs. Shielded Cat 6

We tested the effects of magnetic field interference and ethernet cables. We hooked up two of our four cameras to a shielded Cat 6, and the other two to an unshielded Cat 5, and ran the motors at varying speeds. We noticed that there was a lot more interference on the Cat 5, and decided that although it created a thinner tether, the quality of the image delivered by the shielded Cat 6 was far superior.

I2C extenders

None of our team members have any formal training in computers or software, and we struggled to figure out a suitable form of communication between the topside control box and the ROV. We tried intermittently for months to use I2C extenders. We had tried them in the past, and they sort of worked but were unreliable. We continued with them out of habit, and for lack of an alternative. Luckily, someone eventually accidentally shorted them, and they were dead. In the end, we simply used serial communication through the TX/RX pins on the Arduino and it worked flawlessly through the shielded Cat 6 cable.

Problem Solving

Creating designs from scratch is not without its problems. Ping Engineering views problem solving as an iterative process during the creation and testing of our ROV. We utilize the process of elimination as a key method of identifying and correcting these concerns. We identify what is not working as intended, think of everything that could be causing that problem, test each of the variables one at a time, and fix/replace what is causing the problem. This was shown best in the aforementioned strenuous troubleshooting of one of our cameras, where we needed to test everything, only to find a single channel on our 4-channel balun had given out.

Accounting

Project Budget

Income			
	Source		
HVEA Engineers	Sponsor		**$ 5,000.00**
Expenses			
	Budgeted Value	**Value (Reused or Donated)**	**Actual Cost USD**
Waterproofing	$ 175.00	$ 40.00	$ 149.89
On-Board Electronics	$ 300.00	$ 59.94	$ 260.75
Control Box	$ 250.00	$ 184.88	$ 191.00
Hydraulics	$ 150.00	$ 392.95	$ 91.20
Cameras	$ 175.00	-	$ 146.38
Tether	$ 75.00	$ 64.00	$ 44.32
Frame/ Chassis	$ 200.00	-	$ 198.57
Propulsion	$ 200.00	$ 864.00	$ 144.00
Tools/Misc.	$ 200.00	$ 30.00	$ 158.28
Buoyancy	50.00	$ 10.00	$ -
Travel*	$ 2,568.00		$ 2,568.00
	TTL Budgeted Value	**Re-Used/Donated**	**TTL Actual Cost**
	$ 1,775.00	**$ 1,645.77**	**$ 1,384.39**
Travel to World*	$ 2,568.00		$ 2,568.00
	$ 4,343.00	$ 1,645.77	$ 3,952.39

*Potential travel costs if we make it to the World Competition

References/Acknowledgements

- MATE Ranger reference book
- MATE www.marinetech.org
- MATE youtube/vimeo/facebook videos, product demonstrations etc.
- Homebuilt ROVs. "Homebuilt ROVs Forums"
- Carol Rivera - posting her tutorial tips on Prezi for help with the Marketing Poster https://prezi.com/view/PMT6pwWx4Uu823e8oYz0/

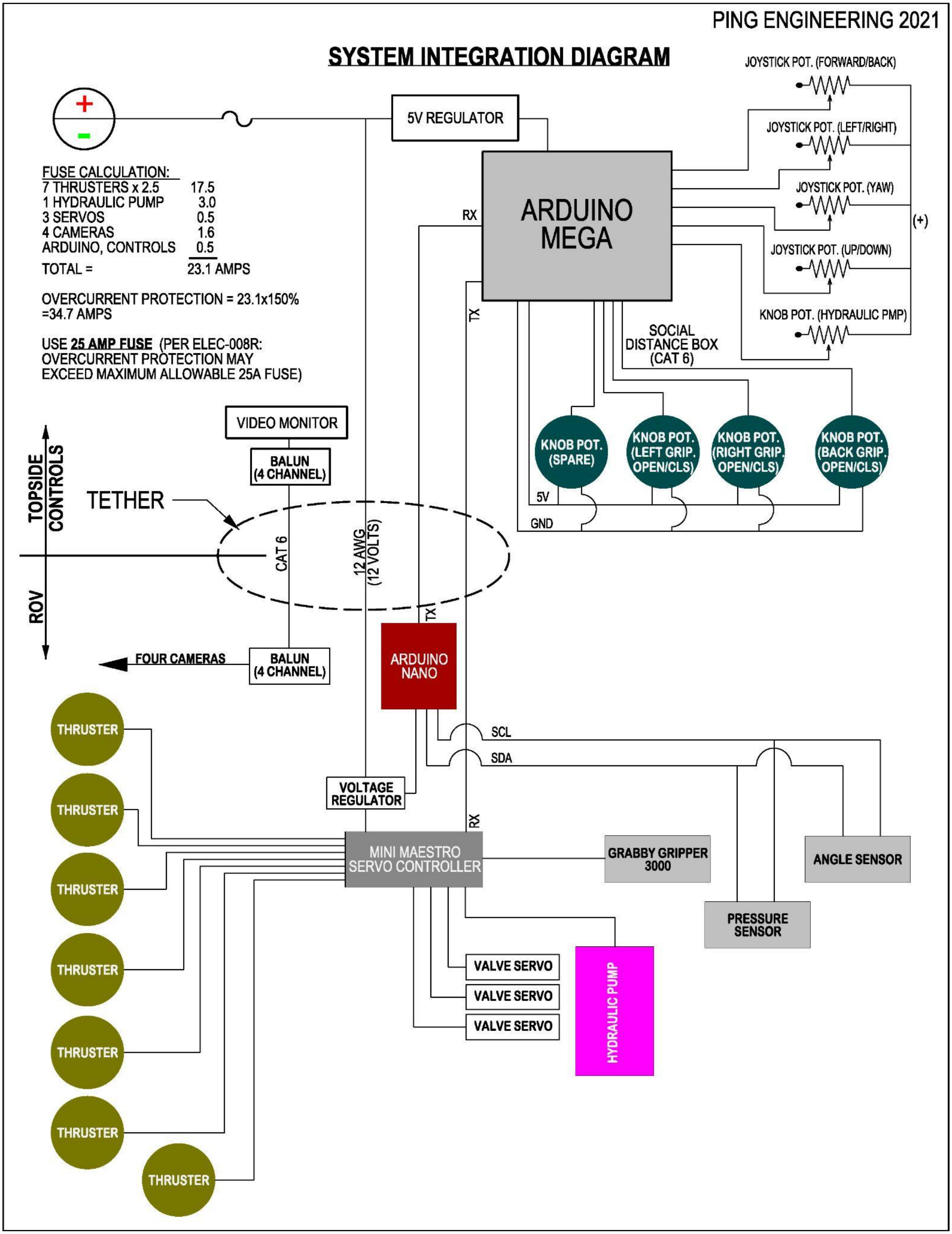
Acknowledgements

We are very appreciative of all of the support we received and want to thank the following individuals and organizations:

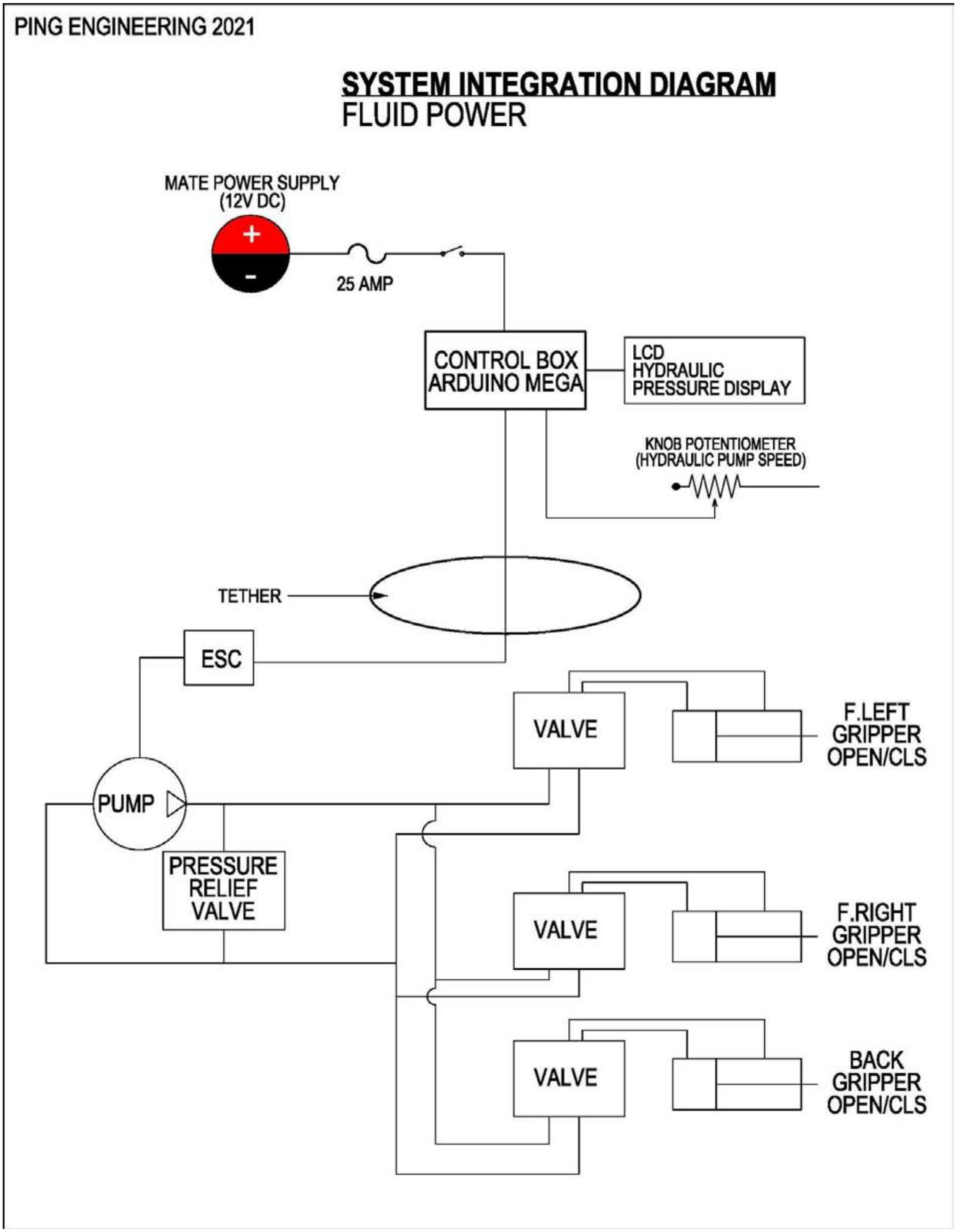
- ❏ Our mentors: Mr. Balison/Mrs. Kennedy for their time and access to the 3D Printer, Metal lathe, their tools, the pool for our practice and demonstration and their goPro
- ❏ Our team sponsor HVEA Engineers for their generous financial support
- ❏ V.Vanessa Morris and Jane White for their MATE PA Regional support
- ❏ Morris Entertainment
- ❏ Pennsylvania Space Grant Consortium
- ❏ Mrs. Cacas for our logo creation
- ❏ Our photographer Eileen Kennedy
- ❏ Tim Pierce's open source downloadable thruster shrouds
- ❏ Our families for all of their support including providing financial support by funding our accommodations and travelling fees to the regional competition in PA
- ❏ The following overall sponsors:

Appendices

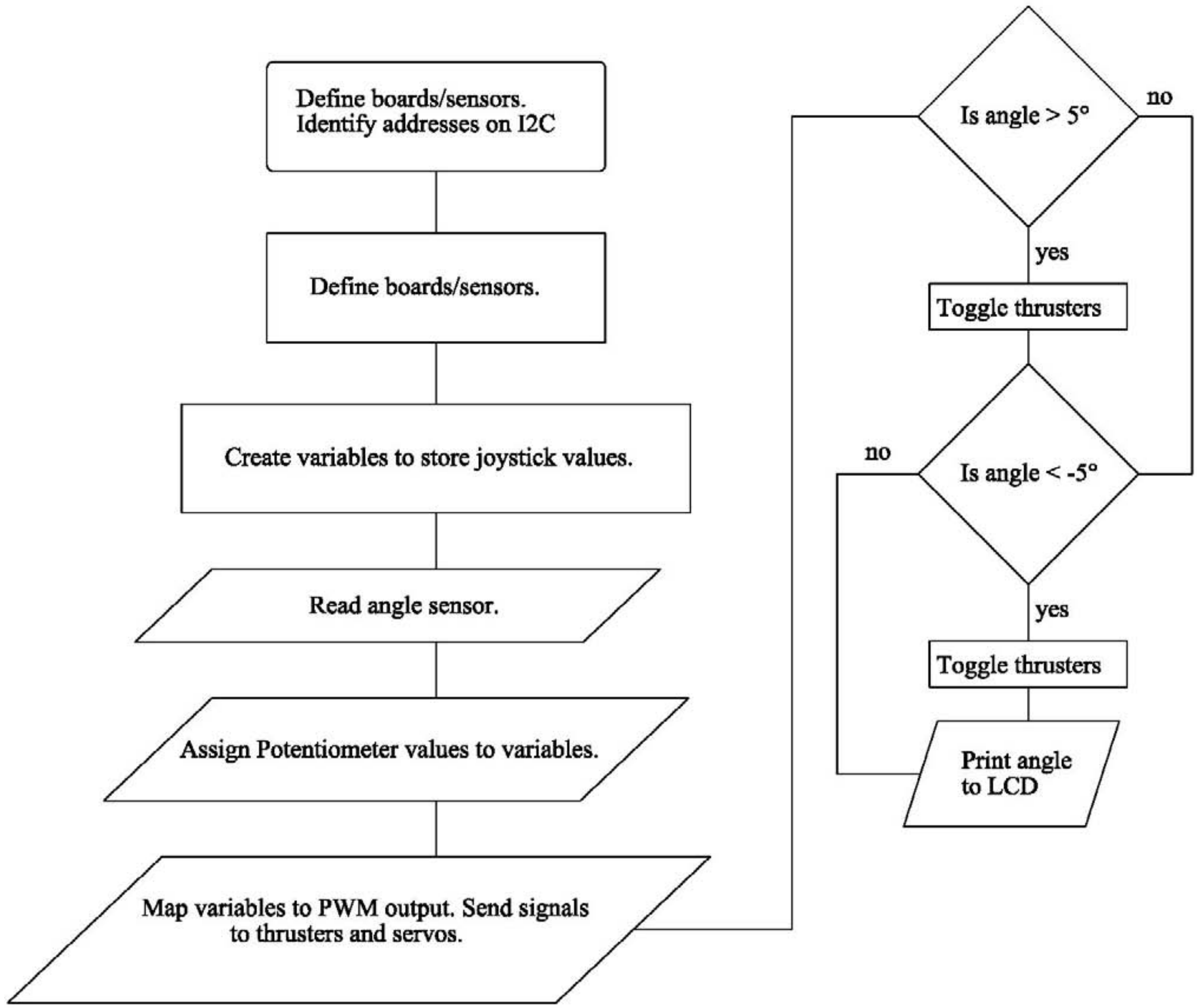
Appendix A: Main Electrical System Integration Diagram (SID)



Appendix B: Fluid SID



Appendix C: Software Flowchart



Appendix D: Gantt Chart

Task Name	October	November	December	January	February	March	April	May
MECHANICAL DESIGN								
Design Frame								
Gripper								
MISSION TOOLS								
Grabber Grippy 3000								
Mesh Net								
PROPULSION								
Attachment of thrusters								
SOFTWARE								
Sensors								
LCD Display								
Motors								
CAMERAS								
Acquisition								
Integration								
BUOYANCY								
Flotation (tether)								
Syntactic Foam								
TETHER								
Creation								
WATERPROOFING								
Cameras								
Sensors								
Corrections								
CONTROL BOX								
Assembly								
COMPANY TASKS								
Presentation								
Documentation								
Budgeting								
Poster								
SAFETY								
Checklist								
Color Scheme								
PRACTICE								
Pool								
Presentation								

Appendix E: Project Cost Accounting

	Item	Qty	Value (Each)	Type	Cost (Purchased)	Value (Reused or Donated)	Total Value
Waterproofing	Dual Wall Heat Shrink Tubing	1	$ 7.89	Purchased	$ 7.89		$ 7.89
	Epoxy Resin, West Systems, Quart	2	$ 45.00	Purchased	$ 45.00		$ 45.00
	Epoxy Hardener, West System, 205, Pint	1	$ 38.00	Purchased	$ 38.00		$ 38.00
	Epoxy Hardener, West System, 206 (slow), Pint	1	$ 38.00	Purchased	$ 38.00		$ 38.00
	Vacuum Port for waterproof testing	1	$ 17.00	Purchased	$ 17.00		$ 17.00
	Cable Penetrators, Blue Robotics	10	$ 4.00	Re-used		$ 40.00	$ 40.00
	Cable Penetrators, Blue Robotics	6	$ 4.00	Purchased	$ 4.00		$ 4.00
	Subtotal				**$ 149.89**	**$ 40.00**	**$ 189.89**
On-Board Electronics	Integra Waterproof Polycarbonate Box	1	$ 56.91	Purchased	$ 56.91		$ 56.91
	Stranded Hook-up Wire 20 AWG	2	$ 14.99	Purchased	$ 14.99		$ 14.99
	I2C Level Converter	1	$ 15.00	Purchased	$ 15.00		$ 15.00
	Bar02 Ultra High Resolution 10 m Depth//Pressure Sensor	1	$ 88.00	Purchased	$ 88.00		$ 88.00
	Adafruit Angle Sensor	1	$ 24.00	Purchased	$ 24.00		$ 24.00
	SparkFun Differential I2C Breakout	1	$ 21.90	Purchased	$ 21.90		$ 21.90
	Voltage Regulator	1	$ 14.99	Re-used		$ 14.99	$ 14.99
	Pololu Mini Maestro Servo Controller, 18 Channel	1	$ 39.95	Purchased	$ 39.95		$ 39.95
	Pololu Motor Controller	1	$ 44.95	Re-used		$ 44.95	$ 44.95
	Subtotal				**$ 260.75**	**$ 59.94**	**$ 320.69**
Control Box	Pelican 1450 Case With Foam (Yellow)	1	$ 99.95	Re-used		$ 99.95	$ 99.95
	3/16 Clear Acrylic PlexiGlass Sheet (12" X 24")	1	$ 19.81	Purchased	$ 19.81		$ 19.81
	45 Amp Anderson Powerpole Connectors (Sets: 10)	1	$ 16.49	Purchased	$ 16.49		$ 16.49
	Powerwerx Retention Clips for PP15/30/45 Powerpole Connectors	5	$ 0.49	Purchased	$ 0.49		$ 0.49
	Powerwerx Panel Mount Digital Blue Volt Meter for 12/24V Systems	1	$ 19.99	Re-used		$ 19.99	$ 19.99
	Powerwerx Panel Mount Housing for Two Powerpole Connectors	1	$ 19.99	Purchased	$ 19.99		$ 19.99
	Red/Black Copper Wire, 10 Gauge, 25 ft.	1	$ 34.34	Purchased	$ 34.34		$ 34.34
	Voltage Regulator	1	$ 14.99	Re-used		$ 14.99	$ 14.99
	Heavy Duty 20A ON/OFF Rocker Toggle Switch, Pack of 5	1	$ 12.99	Purchased	$ 12.99		$ 12.99
	IP67 Waterproof CAT6 RJ45 Feed-Thru Coupler, Case Side	2	$ 9.99	Re-used		$ 19.98	$ 19.98
	Arduino MEGA 2560 Board	1	$ 14.99	Purchased	$ 14.99		$ 14.99
	Screw Terminal Block Breakout Module - for Arduino MEGA-2560	1	$ 32.00	Purchased	$ 32.00		$ 32.00
	SparkFun Differential I2C Breakout	1	$ 21.90	Purchased	$ 21.90		$ 21.90
	Electrical Junction Box	1	$ 6.00	Purchased	$ 6.00		$ 6.00
	Knob Potentiometers - 4 pack	1	$ 12.00	Purchased	$ 12.00		$ 12.00
	Joysticks	3	$ 9.99	Re-used		$ 29.97	
	Subtotal				**$ 191.00**	**$ 184.88**	**$ 375.88**
Hydraulics	Hydraulic Pump	1	$ 101.99	Re-used		$ 101.99	$ 101.99
	Hydraulic Cylinder, 10mm x 50mm	4	$ 47.99	Re-used		$ 191.96	$ 191.96
	Hydraulic Cylinder, 10mm x 80mm	1	$ 52.99	Purchased	$ 52.99		$ 52.99
	Utah Pneumatic 4mm Air/Fluid Tubing	1	$ 15.90	Purchased	$ 15.90		$ 15.90
	3-Way Valve	1	$ 99.00	Re-used		$ 99.00	$ 99.00
	Food Industry Hydraulic Oil	1	$ 22.31	Purchased	$ 22.31		$ 22.31
	Subtotal				**$ 91.20**	**$ 392.95**	**$ 484.15**
Cameras	Foxeer FPV Camera Razer Mini	4	$ 25.99	Purchased	$ 25.99		$ 25.99
	Mini CCTV BNC Video Balun Transceiver Cable (12 pack)	1	$ 12.99	Purchased	$ 12.99		$ 12.99
	Composite Video Cable, RCA Male, Gold plated Connectors, 6 feet	1	$ 10.44	Purchased	$ 10.44		$ 10.44
	4 Channel CCTV Video Quad Splitter Camera Processor System Kit	1	$ 46.99	Purchased	$ 46.99		$ 46.99
	RCA to BNC converters, Pack of 10	1	$ 6.99	Purchased	$ 6.99		$ 6.99
	Foxnovo Screen Capture	1	$ 42.98	Purchased	$ 42.98		
	Subtotal				**$ 146.38**	-	**$ 146.38**
Tether	Hollow Braid Polypropylene Rope	1	$ 22.33	Purchased	$ 22.33		$ 22.33
	Cable Matter Snagless cat 61 Shielded Ethernet Cable	2	$ 21.99	Purchased	$ 21.99		$ 21.99
	10 Gauge Copper Wire, Stranded, 2 conductors, 60 feet	1	$ 64.00	Re-used		$ 64.00	$ 64.00
	Subtotal				**$ 44.32**	**$ 64.00**	**$ 108.32**
e/ sis	Frameless Aluminum Backplate	1	$ 198.57	Purchased	$ 198.57		$ 198.57

Frame/Chassis							
	Subtotal				**$ 198.57**	-	**$ 198.57**
Propulsion	T100 Thruster, Blue Robotics	6	$ 119.00	Re-used		$ 714.00	$ 714.00
	T100 Thruster, Blue Robotics	1	$ 119.00	Purchased	$ 119.00		$ 119.00
	Motor controller, Blue Robotics 30A ESC v2	6	$ 25.00	Re-used		$ 150.00	$ 150.00
	Motor controller, Blue Robotics 30A ESC v3	1	$ 25.00	Purchased	$ 25.00		$ 25.00
	Subtotal				**$ 144.00**	**$ 864.00**	**$ 1,008.00**
Tools/Misc.	HATCHBOX PLA 3D Printer Filament	4	$ 19.99	Purchased	$ 19.99		$ 19.99
	HATCHBOX ECO-ABS 3D Printer Filament	1	$ 19.99	Purchased	$ 19.99		$ 19.99
	12V, 30A Power Supply	1	$ 18.99	Purchased	$ 18.99		$ 18.99
	Screws, Nuts, Hardware - various, stainless steel	1	$ 25.00	Purchased	$ 25.00		$ 25.00
	Belts & Pulleys	15	various	Purchased	$ 68.31		$ 68.31
	Electrician snake	1	$ 30.00	Donated		$ 30.00	$ 30.00
	Velcro	1	$ 6.00	Purchased	$ 6.00		$ 6.00
	Subtotal				**$ 158.28**	**$ 30.00**	**$ 188.28**
Buoyancy	Microspheres, 3M	1	$ 10.00	Donated		$ 10.00	$ 10.00
	Subtotal				-	**$ 10.00**	**$ 10.00**
Travel	Transportation to East Tennessee State University, 647 miles @28 mpg @ $3.05 per gallon x 3 cars			Purchased	$ 423.00		$ 423.00
	Accommodations for mentors 5 nts @$100, believe team members can stay in dorms free			Purchased	$ 500.00	$ -	$ 500.00
	Food ($45 per day * 7 people)			Purchased	$ 1,645.00		$ 1,645.00
					Purchased	**Re-Used/ Donated**	**Total**
	Total ROV cost in USD				**$ 1,384.39**	**$ 1,645.77**	**$ 3,030.16**
	Total Potential Travel Cost if we make it to World Competition				**$ 2,568.00**		**$ 2,568.00**
	Total amount sponsored/funded by HVEA Engineers				**$ 3,952.39**	**$ 1,645.77**	**$ 5,598.16**