HAWKS ENGINEERING

Hoffman Estates High School

Hoffman Estates, Illinois USA

2019 MATE INTERNATIONAL COMPETITION

Ariana Correia: Co-CEO, Fluid Power Engineer, Pilot
11th grade, Hoffman Estates High School

Amber Dellacqua: CFO, Software Engineer, Documentation Manager
11th grade, Hoffman Estates High School

Vanessa Huerta: Tether Manager, Micro-ROV Engineer
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11th grade, Hoffman Estates High School

Mentor: Wayne Oras, Jr.

1. Abstract

HAWKS Engineering has been developing and constructing Remotely Operated Vehicles (ROVs) for five years.

The company's fifth ROV, Nic, is built with Eastman's goals in mind: ensuring public safety, maintaining healthy waterways, and aiding in the preservation of history. Special features of this year's ROV include a hydrodynamic frame which is used to maintain specific thruster alignment and secure the electrical dry housing. In addition, Nic is built with a custom HAWKS Engineering circuit which controls six thrusters, a temperature sensor, and the Micro-ROV.

To accomplish the tasks listed in the 2019 Ranger Manual, Nic is fitted with two pneumatic manipulators, a temperature sensor, stationary hooks, and a Micro-ROV.

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2. Company Information

From Left to Right: Ariana Correia, Amber Dellacqua, Vanessa Huerta, Shraddha Zina

Ariana Correia is a junior at Hoffman Estates High School and this is her second year on the team. This year she was the Co-CEO, Fluid Power Engineer, and Pilot.

Amber Dellacqua is a junior at Hoffman Estates High School and this is her second year on the team. This year she was the CFO, Software Engineer, and Documentation Manager.

Vanessa Huerta is a freshman at Hoffman Estates High School, this is her first year on the team. This year she was the Tether Manager and Micro-ROV Engineer.

Shraddha Zina is a junior at Hoffman Estates High School, this is her second year on the team. This year she was the Co-CEO, Dry Housing Engineer, and Pilot.

3. Mission Theme

Eastern Tennessee, USA, is home to many lakes and waterways. Upon the banks of the South Fork Holston River, on December 13, 1864, the Civil War Battle of Kingsport took place. In addition to the rich heritage of the area, the Boone Dam is highly recognized as an essential part of the community.

A concrete reef ball on the bottom of the Choptank River is home to a Black Sea bass.

Eastman has issued a request for proposal of an ROV that models their “Good for Good” plan. ROVs built for the 2019 competition will not only have to perform in conditions similar to the waterways of Eastern Tennessee, the ROV will have to recover a Civil War era cannon and mark the locations of unexploded cannon shells. Unexploded shells pose a safety threat to the public – by locating the iron balls the EOD (explosive ordnance disposal) unit can be brought in to safely excavate them.

Another need proposed by Eastman, is the focus on rehabilitation of fish habitat and diversity of the South Fork of the Holston River. Ensuring the health of both the water and specimens are part of Eastman’s efforts to operate sustainably and develop more value in the world. An ROV is needed to collected water samples, test the acidity of the water, relocate trout fry raised in labs, and install concrete reef balls at the bottom of the river for fish species like the rainbow trout. By relocating the fry at the bottom of the lake, chances of survival increase due to protection from avian predators flying above.

ROV image of an intake gate.

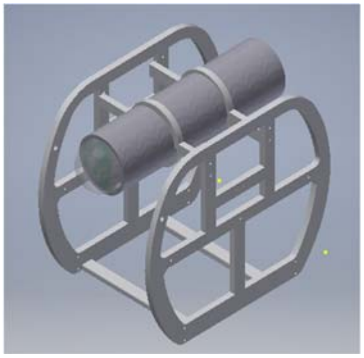
The Boone Dam plays an important role in Eastman’s needs as well. An ROV is needed to locate internal erosion, a process in which voids form within a dam or its foundation because of the interference of flowing groundwater. If the act of flowing groundwater continues, the dam could possibly fail and cause harm to the public. The ROV must be able to conduct routine maintenance on the hydroelectric dam as well. Specifically, the ROV must be able to replace a trash rack, a metal structure that prevents debris from entering the intake of the dam. Locating and filling cracks long the foundation of the dam will be a responsibility of the ROV as well.

4. Design Rationale

HAWKS Engineering had to consider several accommodations in order to fabricate an ROV for use in freshwater environments. Due to the plausibility of maneuvering in small areas, size had to be reduced in order to be able to function efficiently. To enhance mission performance and reduce incompletion of tasks, the company's main focus was directed towards developing physical components instead of altering our revolutionized control system developed last year.

4.1 Frame and Buoyancy

The frame this year was constructed by cutting High Density Polyethylene (HDPE). HDPE is a lightweight durable plastic, which is eco-safe. The material does not emit toxins or other harmful chemicals into water. Anodized aluminum bars were also incorporated in the design of the frame, these bars held in cross-braces. These cross-braces were used to hold the thrusters and attach hooks to the frame. The frame was first designed and modeled in Autodesk Inventor, which made it easy to alter and size hardware before being physically constructed. By creating a three dimensional model of our frame, we were able to adjust the circumference of our Remotely Operated Vehicle (ROV) in order to obtain the most points for the smallest size as well. In addition to online modeling, several prototypes were built out of MDF to guarantee the credibility of calculated measurements.



Autodesk Inventor Assembly of ROV frame and housing.

To determine the buoyant force of the ROV we needed to use Archimedes' Principle. Archimedes stated that the upward buoyant force is equal to the weight of the displaced volume of liquid. To find the volume of the HDPE frame, we submerged a past years HDPE frame with similar dimensions in a tub of water. With the calculated displacement we were able to use the equation Density = Mass/Volume, substituting the mass of the HDPE frame and volume allowed us to compare the density of the frame to the density of water.

4.2 Propulsion

Image of a Blue Robotics T100 Thruster.

The Remotely Operated Vehicle (ROV) is equipped with six T100 Blue Robotics Thrusters (4 horizontal and 2 vertical). To maximize thrust, the four T100 Blue Robotics Thrusters are angled at 45 degrees.

Each thruster has a stationery central stator and a surrounding circular rotor. The stator is made up of a set of electromagnets while the rotor has permanent magnets affixed across its perimeter at certain calculated positions. These electromagnets create a magnetic field in the rotor when the power is switched on and help to rotate the central stator. The brushes change the polarity of the pole to keep the rotation on of the central stator.

Each thruster is controlled with an electronic speed controller (ESC) that was programed with the company's own firmware for best compatibility with the ROV's custom control board.

An image of an old cable penetrator.

4.3 Electronics Housing

The cylindrical electrical housing was donated by Blue Robotics to the previous team. The cylinder has two flanges on either end, lubrication of the O-Rings on the flange is necessary to hold a vacuum. On the front, a dome is screwed into the flange. Taking off this side has been avoided due to potential stripping.

The end cap has 10 holes and 10 penetrators. Each cable that goes into the penetrator was sealed using marine epoxy. This process involved using a syringe to fill the cable casing with epoxy. This was necessary because a split in the casing would create vacuum issues. After potting, the cable was clamped into place and the penetrator was filled. Twenty-four hours was needed for the epoxy to effectively cure.

4.4 Control System

4.4.1 Hardware

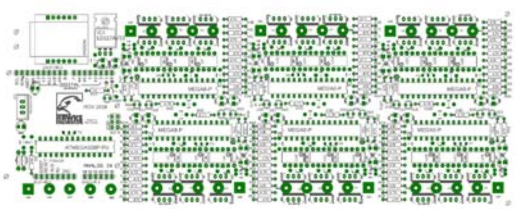


Image of a Gerber file for the HAWKS Engineering PCB.

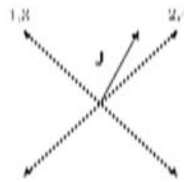
HAWKS Engineering has created a custom electrical board for six brushless motors. The board consists of six electronic speed controllers (ESCs). 36 metal-oxide semiconductor field-effect transistors are soldered in the board (MOSFETs) to control the speed and direction of the motor.

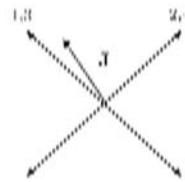
An Arduino compatible processor is also embedded into the board, allowing us to connect other devices such as a temperature sensor and the Micro-ROV.

4.4.2 Software

A Logitech 3D Extreme Pro Joystick is used to control speed and direction of the ROV's thrusters. PyGame, a module that locates and connects a joystick to a laptop, is first initialized in the beginning of the prompt of the ROV's control system. A positive throttle value gives thrust in the forward direction and vice versa. For simplicity, the throttle values that the program initially calculates will have a range of 0 to 1 and will be scaled later. Opposite thruster pairs should always have the same speed, so the program only needs to calculate two values. If the ROV needs to move in a direction closer to the axis belonging to a certain pair, that pair should provide more force. The initial value for the stronger pair is called "a" and the value for the weaker pair is called "b" but the stronger and weaker pairs change based on direction so the program conditionally assigns "a" and "b" to each thruster. Referring to the figure on the next page: In the case on the left, J is closer to the 2,4 axis so thrusters 2 and 4 provide more force and are assigned to be "a." In the case on the right, J is closer to the 1,3 axis so thrusters 1 and 3 provide more force and are assigned to be "a."

$$\frac{\|a + b\|}{\|a + b\|_{max}} - \frac{\|J\|}{\|J\|_{max}}$$





Equation calculating thruster direction and vectors used to determine thrust direction.

4.4.3 Tether

The tether for NIC was designed for efficiency when transporting while also satisfying the proposed safety requirements. The tether is detachable, meaning it disconnects from the electrical housing. It contains two power and ground cables, pneumatic tubes for the manipulators, two Cat5 cables for Ethernet and camera signal, and a rope to reduce potential strain if the ROV needs to be lifted. Cable glands attach and tighten the separated cables for the Cat 5 and power and the air tubes can be detached from the pistons. The tether is mounted on the control station and can be unmounted easily.

Example of a cable gland for a detachable tether.

4.5 Camera System

NIC has four cameras, two outside and two on the inside of the housing. The two cameras on the inside mimic a wide screen vertical view. They are placed on top of each other so the bottom view of the top camera lines up with the top view of the bottom camera. This allows the pilot to see tasks down below and also have a view of what is in front. Regarding the two cameras on the outside, they were specifically placed to aid in accomplishing the tasks in the most efficient way possible. One camera provides a view of two ROV components: a view of the manipulators and the hooks. The other camera attached to the mini ROV provides a different angle for what the ROV is potentially picking up. All four cameras are connected to a video balun, which sends data through a Cat 5 cable to the surface. These signals go through another video balun converting back into specific signals. The individual signals are converted through a channel video multiplexer and sent to a monitor in order to view multiple cameras at one time.

5. Mission Specifics

Several of the 2019 MATE Underwater Robotics Competition tasks call for distinct tools and accessories in order to complete each assignment efficiently. HAWKS Engineering has developed custom made apparatuses which assist our Remotely Operated Vehicle (ROV), Nic, with the assigned missions.

5.1 Manipulators

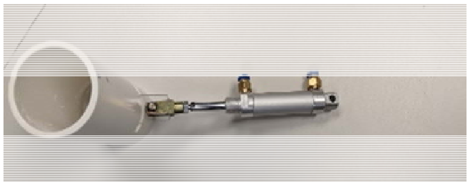


Image of our Trout releasing manipulator.

Our manipulators this year were designed specifically with the integration of a pneumatic system. A polyvinyl chloride (PCV) tube is fitted with a slit, fits a handmade acrylic oval piece that is connected to the end of a pneumatic cylinder. Two different models of this design were accommodated to fit both releasing the grout and fish fry into their designated areas. Each piston is mounted on a cross brace, located at the bottom of the frame. Connected to each of these pistons, are tubes which connect to valve switch and an air compressor located on our system control cart.

5.2 Hooks

The hooks on the ROV have been designed specifically based on the tasks that could not be accomplished by the pneumatic manipulator. It was decided that hooks would be used instead of a traditional claw manipulator based on the specifics of the product demonstration. It was more efficient to use hooks for the numerous tasks that had to be lifted based on the fact that most of those tasks had to be lifted from respective U-bolts.

5.3 Micro- ROV

Image of Little Jimmy.

A Micro-ROV, named Little Jimmy, was designed this year to inspect a 6 inch corrugated drain pipe for indications of possible dam failure. Paired with a light and camera, the Micro-ROV can identify areas of the pipe filled with muddy water flow.

HAWKS Engineering has built a Micro-ROV constructed with a past year's bilge pump motor. Little Jimmy is connected to a motor controller which is wired to the main ROV's PCB. Little Jimmy's movements can be controlled through the Logitech 3D Pro Joystick. When a button on the joystick is pressed, Little Jimmy can go forward or backwards. A light source is also connected to the Main ROV's electronics board, with the addition of a camera feeding off from the main camera system.

The frame of the Micro-ROV was first constructed out of cardboard, once the dimensions were finalized the Micro-ROV was modeled in Autodesk Inventor. Then the frame was cut out of MDF on a ShopBot, stainless steel brackets and machine screws were then fitted as well. The final frame for the Micro-ROV was cut out of High Density Polyethylene (HDPE), an environmentally friendly plastic, on the ShopBot as well.

5.4 Temperature Sensor

A Blue Robotics Celsius Fast-Response, ±0.1°C Temperature Sensor, was fitted on the ROV this year to aid in reading temperature of a specific location at the bottom of the pool. The sensor

Image of Blue Robotics Celsius Temperature.

is fitted with an anodized aluminum cage, which protects the sensor from damage. A cable penetrator based design allows us to screw the sensor into the side of the ROV's frame. The temperature sensor is supported by 3.3V logic, therefore a level shifter was needed to convert 5V from the main HAWKS Engineering PCB to the sensor. The temperature sensor is supported through python code based on Blue Robotics' TSYS01 library, the code itself is embedded in the ROV's main program.

6. Fabrication

Fabrication is mentioned in each section specifically. Tools used to create each component include a ShopBot, table saw, band saw, horizontal belt sander, files, drills, hand screw drivers, nut drivers, 3D printer, laser cutter, metal working tools, etc.

7. Testing

Each individual camera was jumped with wires through the balun to see if all the solder connections in between were satisfactory. This also determined if the video balun, Cat 5, and converters were good or not. Relating to more meticulous problems, the two cameras in the housing have small white connectors that are extremely easy to break so those also had to be occasionally jumped for testing.

Regarding the dry housing, to test the ability of each penetrator to hold up underwater a vacuum was created using the pump and a gauge and then held for several minutes. If the gauge hand moved, then it could be assumed to be because one of the penetrators was not tightened enough or was not sealed properly.

8. Safety

8.1 Safety Philosophy

Safety is one of HAWKS Engineering's main concerns as a company. Not only is the safety of the individual our main focus, the safety of the vehicle and surroundings are extremely important as well.

8.2 Safety in the Woodshop

While building the ROV, there were many safety procedures in place to avoid injury. Upon entering the woodshop, closed shoes needed to be worn along with hair pulled up. Every time a member went to use one of the tools in the woodshop, whether if they were using the belt sander or drilling into pieces of aluminum for the frame, they needed to wear eye protection. When metal was grinded for various components for the frame, gloves needed to be worn. Heavy objects needed to be lifted by more than one person as well.

8.3 Safety Features

On the frame, all edges were filed and sanded down. The tether cables were strapped away from the thrusters, the tether was encased in mesh to avoid unnecessary tangling and user injury. Thruster shrouds were 3d printed to avoid objects from interfering and getting caught in the propellers. The overall design of the hooks, Micro-ROV, and cameras are packed inside the frame to avoid catching or tugging on potential surrounding items.

Each penetrator on the housing was tightened but not over tightened based on Blue Robotics specifications to ensure a safely sealed housing. Along with this, each penetrator has been potted with epoxy to ensure no leakage. The glands at the detachable part of the tether are hand tightened and some are epoxied for a stronger seal. They also provide strain relief for the tether since it does not have a cable directly going to the housing without another mechanical component reducing the strain.

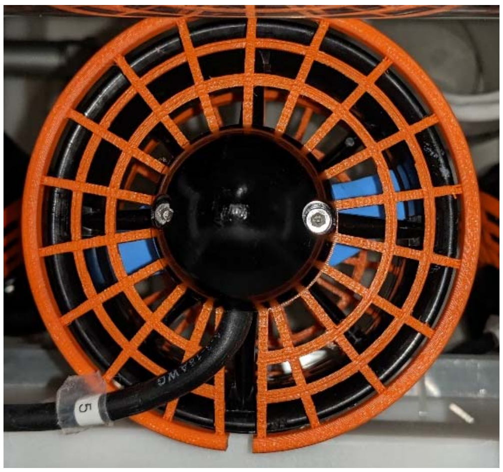


Image of a shroud for thruster.

Regarding the inside of the housing, the board in the housing is attached to the flange so it is not moving around, which avoids potential electrical discharge. The flanges on the electronics housing are designed to release if the pressure is too great.

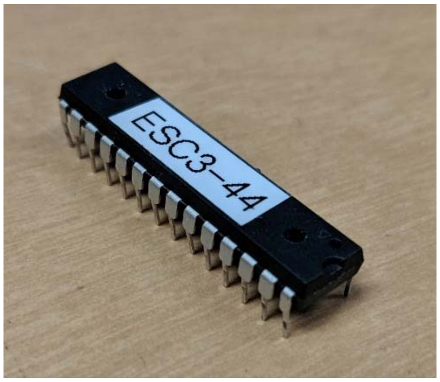
On the electrical items, all the smaller electrical boards are wrapped in kapton tape to ensure no electrical discharge takes place. The main board was created with voltage regulators to protect itself from high voltage values. All the wires are insulated with heat shrink or have electrical tape covering them. The Cat 5 connectors are strapped down with electrical tape from issues of them slipping out and to ensure the metal connection does not touch and create electrical discharge

AC power is clearly labeled to not be present and DC power is labeled accordingly.

9. Troubleshooting

HAWKS Engineering knew from previous experiences with the board that possible sources of error included the ESC chips and solder connections. ESC chips can be switched out with spare pre-programmed ones. When unsure, the team would use a digital meter to trace their steps in the circuit. Another source of grievance was the CAT5 connector, which was hand crimped. If the problem had to be narrowed down even more, another board was tested. Complementing electrical troubleshooting, software also needed to be tested by using different programs to see if the programs were causing different issues for the thrusters or board.

From reusing and changing the previous year's camera system, numerous problems occurred. All types of problems occurred and were fixed. Ranging from not turning on to being powered but with ghosting on the monitor. In order to find a problem, tests needed to be done to



Occasionally, ESCs would malfunction and need to be replaced.

narrow down the issue. Whole camera tests were needed at a point for testing the outside cameras. More problems were created by opening up the cameras. By using a new camera, the electrical team could see if a camera was potentially burned out. Possible minor issues up above in the control station could have caused the cameras to malfunction, such as power converters not going to the right equipment, multiplexer being on the wrong setting, and BNC connectors being in an incorrect position.

After discovering that a vacuum had not been held and the source of the issue was not clearly visible, the team created a vacuum whilst holding the penetrators in water. HAWKS Engineering could see inside the transparent housing when water would travel from the origin of the leak to the inside of the cylinder. From this process, the company was able to find which penetrator and which part of the cable was in need of resealing. When it seemed that the flange was the issue and not the penetrators, a 'soapy water' test was performed. A mixture of water and soap was sprayed onto the section where the flange and cylinder met. If any bubbles from the soapsuds appeared inside the housing, then it could be concluded that the flange had a problem holding a vacuum.

10. Team and Organization

10.1 Project Management

HAWKS Engineering tried their best at the start of each week, to gather everyone's schedules, and decide when meetings should occur. Goals were written at the beginning of each Monday meeting and were expected to be accomplished by the end of the following week.

10.2 Challenges

This year, inexperience played against our team. Having a short amount of time to understand new material made it difficult to reach deadlines and caused a lot of technical errors to occur.

Communication also became difficult in times of disagreement.

10.2.1 Interpersonal

Every company encounters issues, our team was no exception. Altercations were too common between members as deadlines approached. Members often made excuses and pointed the blame to other employees when a problem occurred. This often led to no one talking to each other for a while resulting in communication that wasn't very clear amongst members. Team members were often left out of important conversations and decisions, this caused a lot of problems with the schedule time for production of specific ROV components.

10.2.2 Lessons Learned

As a group of four individuals, this year we were encouraged to step outside of our comfort zones and learn new things.

11. Future Developments

In the future, HAWKS Engineering hopes to further develop their mechanical components. For the last four years, the company has been focusing on innovating and developing an efficient software for the ROV's thrusters. Less attention had been previously placed upon a manipulator and stationary hooks, which often led to the component not being done until a few weeks before competition.

HAWKS Engineering also looks forward to one day successfully waterproof their own housing – past years have attempted this, but were left with numerous leaks and damaged electronics.

12. Finance

12.1 Budget and Project Cost

Since HAWKS Engineering is associated with Hoffman Estates High School, most of our materials and parts were bought using grants from District 211 Township. With limited money for supplies, HAWKS Engineering did not want to spend more $3000.00 on the project.

The table below contains all of the supplies bought or donated for the construction of Nic and Little Jimmy, coming to a final total of how much our company spent.

Category	**Amount Spent (USD)**	**Donated/Discounted**	**Market Value**
Frame/ Manipulators	$375.03		$385.03
6ft Aluminum C channel	$9.39	N/A	$9.39
100 Washers	$4.53	N/A	$4.53
100 Nuts	$3.77	N/A	$3.77
Stainless Steel Screws	$11.53	N/A	$11.53
HDPE plastic (4' X8')	$210.00	N/A	$210.00
HDPE plastic (12" x 12")	$0.00	Donated	$10.00
Hook	$6.00	N/A	$6.00
Pneumatic Cylinders	$80.54	N/A	$80.54
Solenoid Valve Switches	$31.77	N/A	$31.77
Tubing	$17.50	N/A	$17.50

Propulsion	$620.00		$853.00
6 T100 Blue Robotics Thrusters	$600.00	Discounted	$833.00
Bilge Pump Motor	$20.00	N/A	$20.00
Electrical Housing	$178.00		$243.00
4" Acrylic Dome End Cap	$39.00	N/A	$39.00
4" Acrylic Tube	$0.00	Donated	$65.00
4" Acrylic End Cap with 10 Holes	$24.00	N/A	$24.00
4" O- Ring Flange	$29.00	N/A	$29.00
Cable Penetrators	$40.00	N/A	$40.00
Marine Epoxy	$16.00	N/A	$16.00
Cable Glands	$30.00	N/A	$30.00
Control Station	$333.76		$333.76
Cameras	$28.56	N/A	$28.56
Router	$49.85	N/A	$49.85
Monitor	$0.00	Donated	$0.00
Multiplexer	$49.99	N/A	$49.99
VGA	$5.36	N/A	$5.36
Power Supply	$200.00	N/A	$200.00
Control System	$689.75		$689.75
10 Circuit Boards	$100.00	N/A	$100.00
Electrical Components	$500.00	N/A	$500.00
Logic Level Shifter	$5.00	N/A	$5.00
Logitech 3D Extreme Pro Joystick	$28.75	N/A	$28.75
Temperature Sensor	$56.00	N/A	$56.00

Tether	$95.00		$95.00
100’ Mesh cable	$20.00	N/A	$20.00
Wires	$75.00	N/A	$75.00
Registration Fees	$200.00	Grant	$200.00
Totals	**$2520.07**		**$2799.54**

13. Acknowledgements

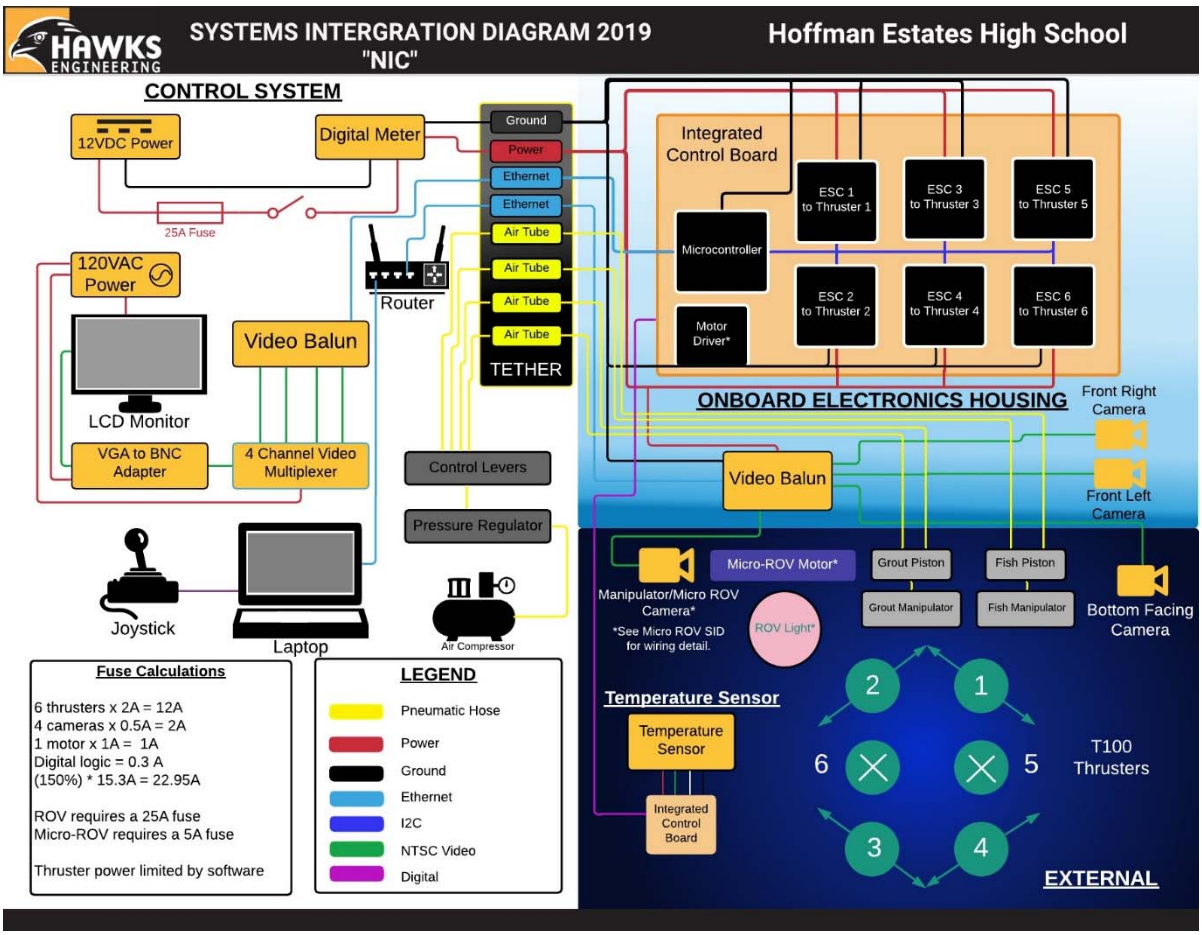
HAWKS Engineering would like to thank the following companies and organizations for their generous help and donations to support the development of our Remotely Operated Vehicle (ROV), Nic. We want to also thank our mentor, and Engineering Teacher, Mr.Oras for staying after school and coming in during weekends to let us work on NIC. HAWKS Engineering would also like to recognize their families and the janitorial staff for the endless encouragement and positivity during the journey of building Nic. Lastly, we would like to thank Mr. Jim Nicolaisen for donating a vacuum pump and sharing his wisdom with our team over the years. In honor of his commitment to our company, our main ROV, Nic, was named after him and the Micro-ROV, Little Jimmy, was named after his son, who also works in our building.

14. References

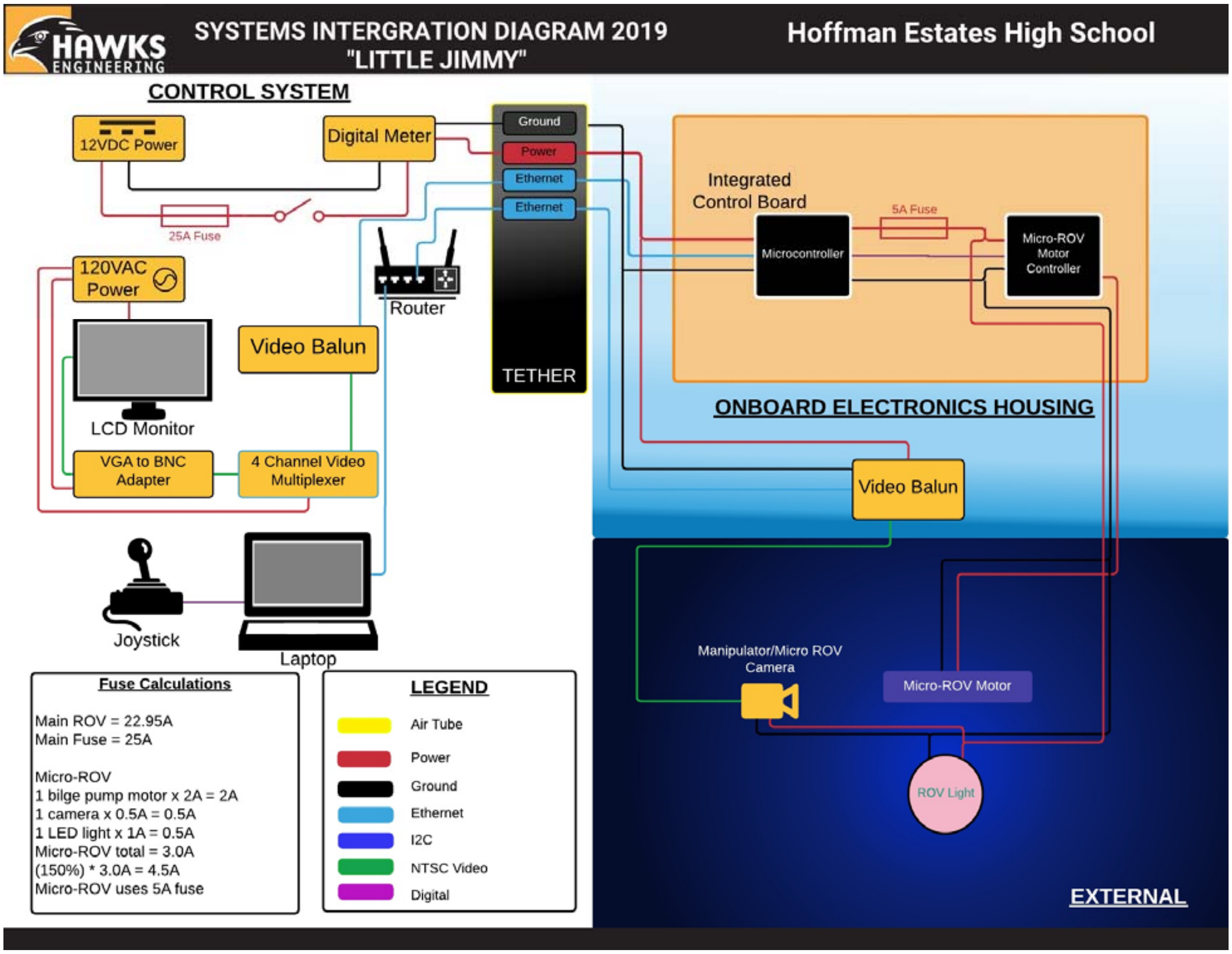
Https://Www.cbf.org/Document-Library/Cbf-Publications-Brochures-Articles/ReefballSheet_RevisedJune15d507.Pdf.

"Water Intake Maintenance | Using an Underwater Drone." *Deep Trekker*, 6 July 2017, www.deeptrekker.com/water-intake-maintenance/.

Appendix 1: Systems Integration Diagram (SID)

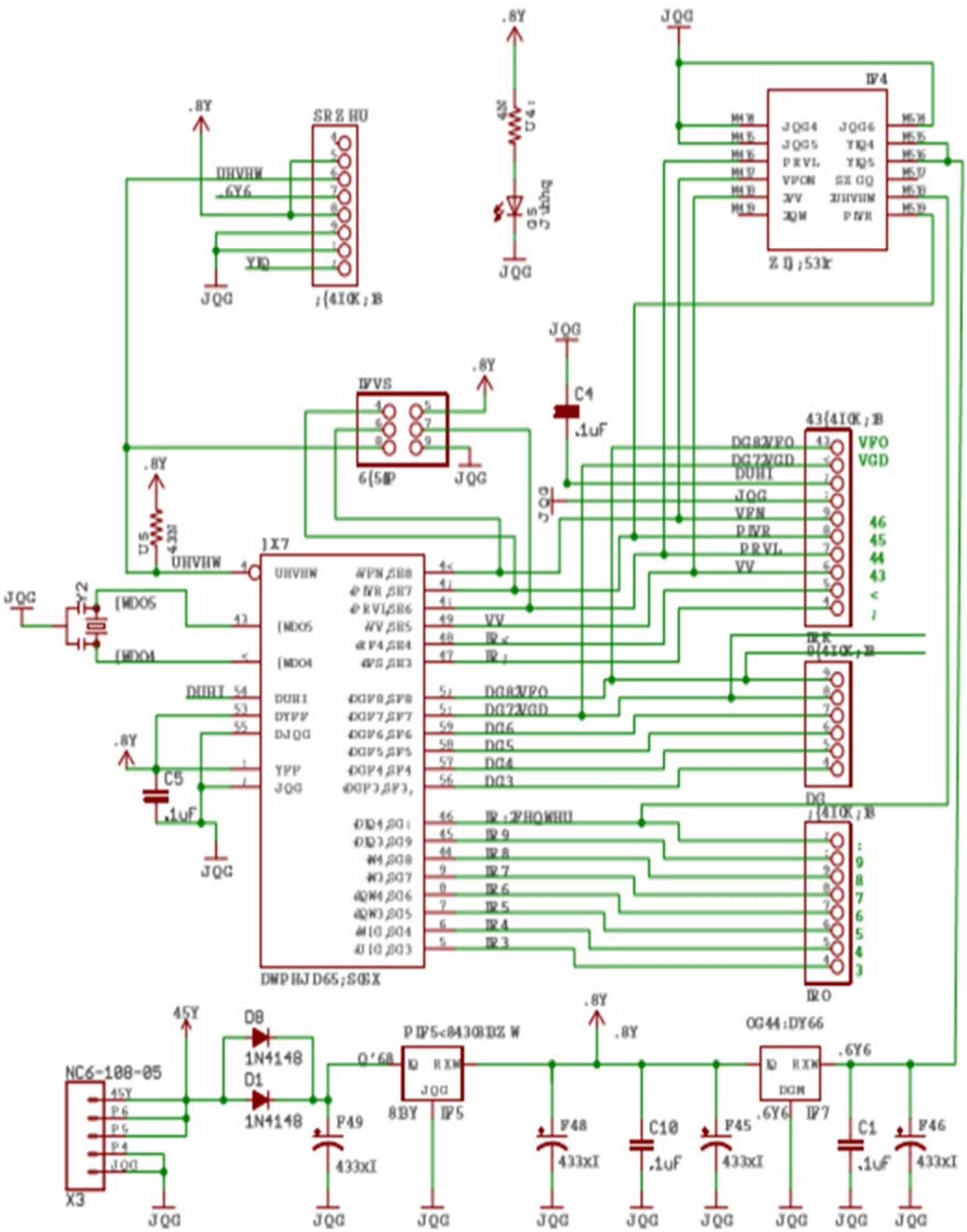


Appendix 2: Micro-ROV SID

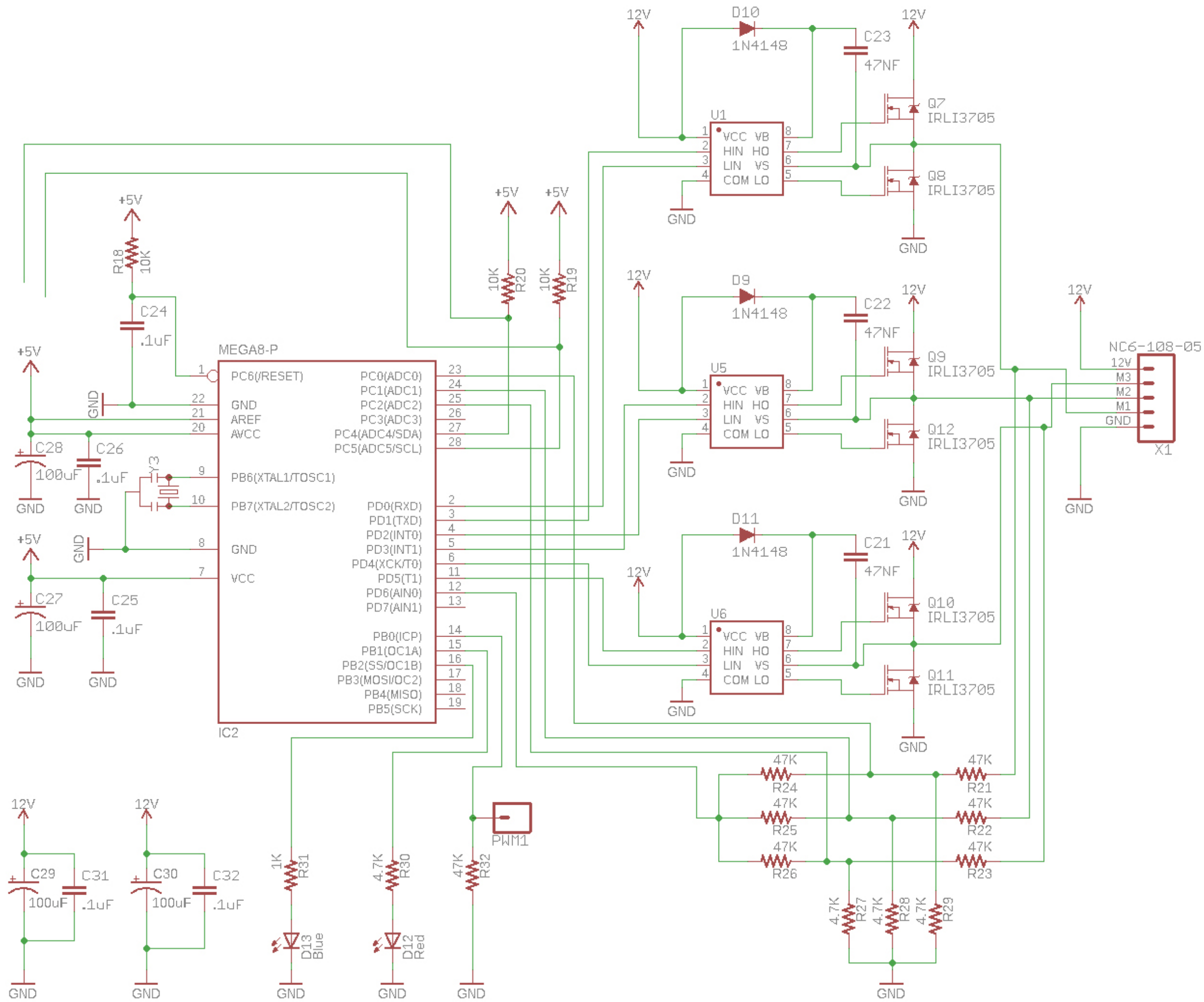


Appendix 3: Electrical Schematics

Below is a schematic of the Arduino compatible microcontroller on HAWKS Engineering's custom electric circuit board.



Below is a schematic of one ESC on HAWKS Engineering's custom electric circuit board. This circuit is duplicated for six thrusters, each programmed with a dedicated address.



Appendix 4: Safety and Operation Checklist

<u>In workshop:</u>

- Proper safety gear for specific situation is worn
- Area clear of tripping hazards
- Equipment kept properly
- Keep the workshop clean
- Always have someone working alongside with in the workshop

Soldering:

- Wear safety glasses
- Work in a clear area

<u>On deck:</u>

Setting up:

- Clear the area
- Tether is attached securely and being managed
- All components are in power strip
- Power supply is off
- No exposed wires
- Screws and nuts are tight
- Single inline 25A fuse is in place

Power-up:

- Ensure team members are attentive
- Tell the team “power on”
- Power on
- Monitor and control station up and running
- Perform thruster test
- Check video feeds
- Test pneumatic manipulators

Launch:

- Notify the team that launching is initiating
- Crew members handling ROV call out “ready”
- Launch ROV

ROV Retrieval:

- Pilot announces ascension
- Deck crew waits for thrusters to be stopped
- ROV is carefully lifted from the water

Loss of Communication:

- Restart ROV
- Check if there are any red lights on the board
- Restart program
- Resume mission if communication is restored

Maintenance:

- Check if the thruster guards are spinning freely
- Check if there is any damage to any of the components
- All cables are neatly secured
- Screws and nuts are tight