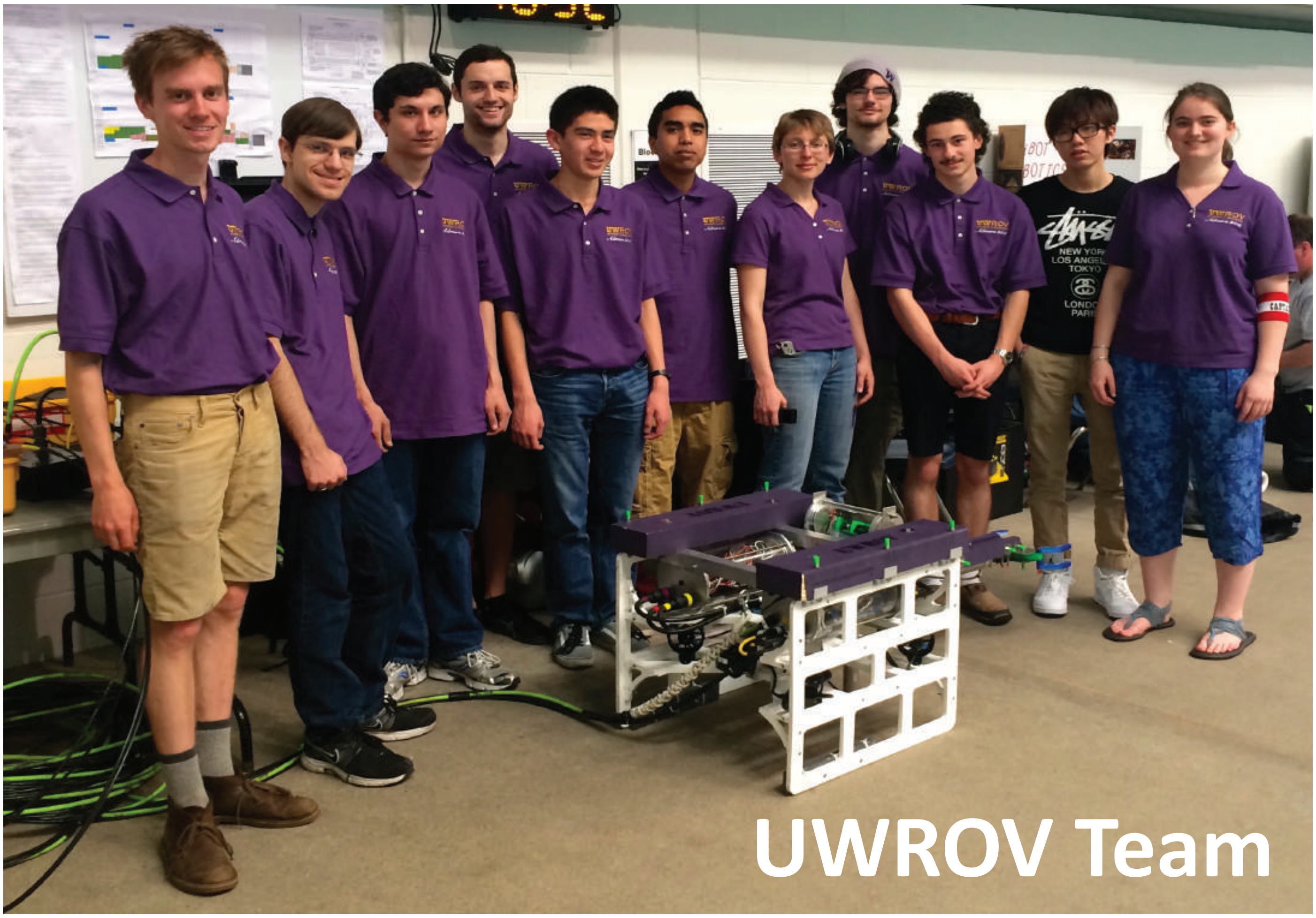
UWROV

2015 International MATE ROV Competition
Explorer Class
St. John's, Newfoundland, Canada

UWROV
Seattle, Washington, USA

UNIVERSITY *of* WASHINGTON

UWROV



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Abstract

Admare was designed to complete missions planned for the 2015 Marine Advanced Technology and Education (MATE) International Remotely Operated Vehicle (ROV) Competition. This vehicle is also intended for use in a variety of research opportunities through the University of Washington for students and faculty. As such, ROV Admare was designed to be more robust for long missions and greater depths. The vehicle meets MATE safety requirements and is capable of being deployed from a ship. Admare was built for the primary objective of completing missions in an Arctic environment such as conducting science through observation and collection under ice, pipeline inspection and repair, and maintenance and repair of oil fields. While these tasks are more specialized, Admare was designed to be versatile, allowing for changing instrumentation on board and being able to complete various tasks in a range of environments. Some features of Admare consist of a (detachable) tether management system, dual system cameras, syntactic foam for buoyancy, graphical user interface (GUI) to display system stats, and a rotating manipulator arm with interchangeable finger systems.

Figure 1. Admare, UWROV's 2015 ROV being driven in Portage Bay, Seattle, WA.

Budget

The building of Admare was made possible through the generous donations by sponsors both inside and outside the University of Washington. About half of the team's income was made through the donation of parts and pieces from local and national companies. Some parts donated include the Starboard for the frame, the aluminum for the endcaps, and the acrylic for the pressure holds. The other half of the funding was raised by meeting with potential sponsors and presenting our company to them as an investment. Some of our major sponsors include Boeing and various departments within the University of Washington.

The overall budget for Admare was envisioned at the beginning of the year to be $10,000, with a majority of funds raised throughout the year. Overall, the budget was followed with the totals for the vehicle being $9,752.52.

In regards to budgeting for travel, five team members are attending the International MATE Competition. We originally budgeted for six members to attend the International Competition, however with the increased expenses of travel arrangements, the amount of members going was cut to five. As the competition is being held in Canada, travel is expensive and so costs are almost the equivalent of the vehicle. The travel money was raised through a crowd funding campaign, USEED, with the generous donations from our community.

Administration	$170
Electrical Engineering	$2,176.61
Mechanical Engineering	$1,129.84
Computer Programming	$535.75
Travel	$9,015.00
Other	$491.13
Donation of Parts	$5,000.00
Shipping	$142.20
Taxes	$106.99

Figure 2. UWROV Expenses.

Design Rationale

Each of the decisions made for Admare were calculated. Keeping in mind both the mission parameters and the envisioned future of Admare working with professors and students from the University of Washington to do research, Admare was built to fulfill these dreams.

Shape and Frame

The overall shape and structure of the frame is based on the frame and pressure housing designs used successfully on UWROV's 2014 Orcus design. Admare will be an ROV in progress for two years, a test bench for new sub-systems that will be applied to many new challenges. The design intent was to provide a large, robust framework with high-quality thrusters, cameras, and electronics that could support a wide range of subsystems over a minimum of two years.

The ROV uses a traditional rectangular shaped frame. It uses two vertical sides to support two horizontal decks, a double H frame, making Admare taller and gaining a deck over the Orcus design used previously. Overall dimensions are 66 cm wide, 66 cm long, and 61 cm tall. These large, unobstructed surface areas inside the vehicle give us a wide range of space and configuration possibilities to safely anchor the different mounting systems that keep subsystems safely secured within the vehicle.

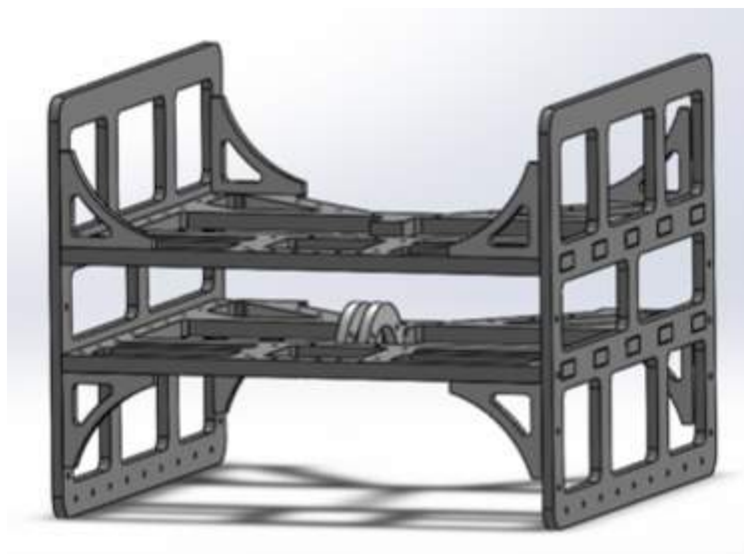

Figure 3. Three-dimensional rendering of Admare's Frame design.

The frame material chosen was King Starboard (HDPE) because it is slightly buoyant, non-corrosive, and non-metallic. HDPE can be safer to work around than cut aluminum sheet because it is less likely to have sharp edges that cut hands. HDPE has a manufacturing advantage because it is easy to fabricate with a water-jet, bandsaw, drill, or mill. One of the few drawbacks is that is has a higher flexibility compared to rigid metal plates. Strong forces can cause unwanted flex, bend, or rotation and can cause permanent deformation of the material.

Manufacturing the frame

Our team chose water-jet cutting as the primary fabrication process for the frame. This saved a large amount of machining time - to mill, drill or otherwise hand manufacture these parts would have taken dozens of shop hours. The precision of water-jet manufacturing also allowed us to easily include some nice details in our framework: pre-cut holes for cable management, zip-ties, and screws. Manufacturing by water jet increased how efficiently we could utilize our sheets of material by allowing mounting brackets and angle brackets to be nested into the “dead” spaces where we placed holes in the frame. Using more traditional machining methods, the majority of that material would have been chewed up by cutting tools.

Example of problem solving: The frame material flexed to unacceptable deflection distances under the forces of the manipulator arm being rotated. The deflection of the two horizontal decks allowed the rack and pinion gears rotating the manipulator base to become unmeshed. One of our team members installed two strong, rigid aluminum u-channels under the top platform. We specifically chose the u-channel shape for its high resistance to bending movements.

Lesson learned: To place the screws on a curved surface, it is necessary to provide a cut-back, flat surface to drill the screw down into the material. Not recognizing this left our team hand-cutting those flat spaces for the screws on the curved angle brackets, which was very time-expensive.

Hardware

The ROV Fasteners are stainless steel bolts, nylock nuts, and loctited to prevent the nuts from loosening during travel and operation. A pro of using loctite is that it is more secure than epoxy, but it is unfortunately expensive. Another issue is that some of the bolts may be the wrong length and creating potential snag and injury points. Purchasing the right hardware is crucial to the long-term security of joined pieces. The mechanical team invested a significant portion of its budget in purchasing the right hardware for each application.

Thrusters

The large frame of the ROV requires more power than we had needed in the past. In order to have four degrees of freedom we decided on a six motor system, four mounted horizontally and two mounted vertically. To ensure space for six motors, we either had to dedicate a large portion of the vehicle to the motors or find smaller motors than used in the past. This led us to the Blue Robotics T100 thruster, a brushless motor that is half the size of our previous brushed motors but capable of equal thrust output. The T100 thrusters are nearly symmetrical in directional thrust, outputting up to 5.2 lbf forward and 4 lbf reversed. This allows for our diagonal motor arrangement which takes advantage of all four horizontal thrusters whenever strafing or moving in the camera’s direction.

Example of problem solving: Exposed bolt tails are a hand safety and entanglement hazard. It is difficult to purchase bolts that are exactly the right length for every position, but it is possible to cut down excessive bolt tails and install vinyl screw caps to protect crew members from being harmed.

Lesson learned: This was the first underwater project for most of our ME team, and we all had to learn the correct grades of fastener material to place underwater. We learned that aluminum screws are corrosion resistant, but not strong enough. We learned that zinc-coated steel screws are not sufficiently corrosive-resistant. Stainless steel hardware is the right mix of strength and corrosion resistance.

Lesson learned: Choosing flat-top machine screws gives a very safe, smooth outer surface, but comes with the time cost of hand-drilling the countersink at every screw position. Bolts are faster to install and are usually easier to remove, but the bolt head does stick out from the vehicle surface.

Figure 4. The returned and fixed Blue Robotics thruster.

Each thruster is capable of drawing 130 W at 12 V at full power, so operating all six motors at full power would exceed the power limitations of our converters. To mitigate this we limit each motor to 4.5 A (54 W) via the control system to ensure reliable operation of the motor system. Even when idle the motors and motor drivers still account for the majority of the total power consumed by the ROV, so motor efficiency is critical to minimizing power usage. By using brushless motors, which are more efficient but more expensive than their brushed counterparts, we are able to increase the thrust we get from the limited power supply. Considering their smaller submersed weight and high efficiency, the brushless T100 thrusters fit our needs better than any other thruster on the market.

Four thrusters were chosen for forward/reverse and turning, two thrusters for vertical. All thrusters are encased within the vehicle. The layout of the motors within the vehicle mimics industry ROVs and has been an efficient and successful layout for past team vehicles.

Buoyancy

Ballasts were deliberately created to be a simple design - two vehicle-length, rectangular pieces of syntactic foam in a symmetric configuration. The foam is mounted on top and out to the sides to keep the center of buoyancy as high in the vehicle as possible. A high center of buoyancy over a low center of gravity provides stability in the water to keep the vehicle from rolling. Another deliberate choice that affected the buoyancy was to place the pressure holds for electronics and cameras on the top deck of the ROV. These are objects that contribute a large positive buoyancy effect, and having

Example of problem solving: The ROVs center of gravity was displaced when the manipulator was placed on the front. Buoyancy foam was placed around the end of the arm to bring the manipulator up to a level position, correcting the ROVs center of gravity.

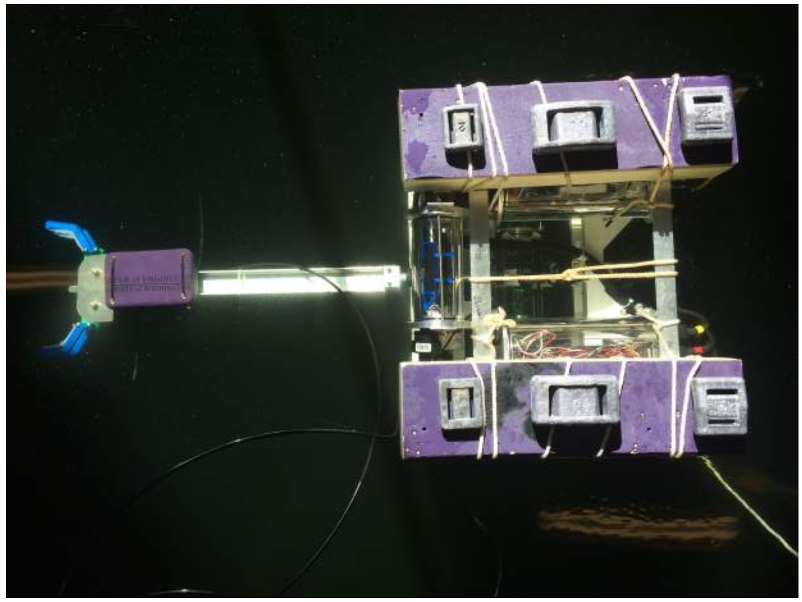

Figure 5. Admare buoyancy testing using dive weights to determine the amount of Syntactic foam to be neutrally buoyant.

them near the top contributed to keeping the center of buoyancy high above the center of gravity.

We chose a volume of foam that would leave the ROV about 6.8 kg positively buoyant and then added 6.8 kg of ballast lead weight to bring it to neutral buoyancy. Our intent is to add onboard systems next year that will add to the weight of the vehicle - this will allow us flexibility to add approximately 6.8 kg of equipment by just removing the lead weight. The symmetric foam blocks combined with non-symmetric electronics holds made the vehicle slightly imbalanced from left to right, but this was fixed by the placement of lead weight along the bottom sides of the frame.

The syntactic foam was recycled from scraps left from a previous ROV. It was cut down to the amount we needed with very few cuts, keeping several pieces largely intact for use in future vehicles.

Pressure holds

The designs used on Orcus last year were effective and as such we recreated the acrylic tubes with aluminum 6061 endcaps for Admare. 6000-series aluminum alloy is bonded with magnesium and silica for known for its high strength to weight ratio and corrosion resistance. 6061 aluminum is also used in Luxfer scuba tanks we used to power the pneumatics system, verifying the alloy's superior performance in a myriad of applications. Used industry standard connectors. A vacuum plug allows the pressure hold to be vacated to very low pressure. This increases the pressure differential between the inside and outside of the hold, helping the outside pressure hold the end cap onto the pressure hold and preventing leaks.

Manipulator

The mission requires the ROV to pick up, place, remove and manipulate objects in the marine environment. We believed that a manipulator arm with interchangeable "fingers" was the most adaptable single tool we could include on the ROV to complete the widest number of tasks. This was the focus of the mechanical design team.

The manipulator arm includes a rack and pinion gear at the base mount to rotate the arm through 180 degrees. The rack and pinion gear is moved by a double-acting pneumatic linear actuator. Two needle valves control the air flow to the two sides of this piston and allow us to rotate the arm and stop it at any point in the 180 degrees of rotation. This allows our manipulator arm to be rotated to the optimum approach angle to complete a task.

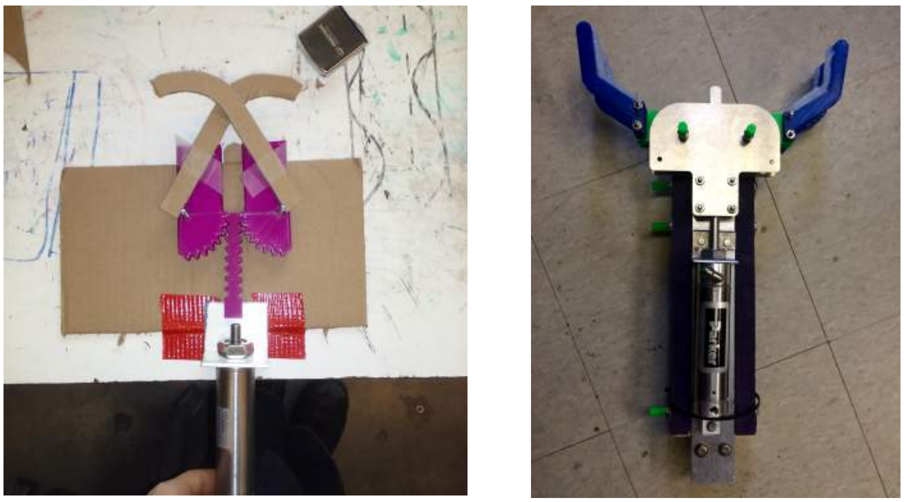

Figure 6. Prototype of manipulator (left) and final product (right).

The manipulator's claw is powered by a single-acting, spring-extend pneumatic linear actuator. The forward movement of a straight gear rotates a gear for both of the "finger" sets. We chose to use a spring-extend for the safety of the vehicle. If the pneumatic power is lost, this piston will spring forward, pushing the gears to open the claw and releasing the ROV arm from the object it was holding. If we had chosen a spring-retracting system, it would be possible for the ROV to lose pneumatic power and be stuck under the water, continuously holding onto the object that was in the claw if power failed. Using the spring-extend to hold the claw open also provides the additional advantage that the work of holding the claw closed is done by the air pressure, which can exert a greater force than the mechanical spring.

> **Lesson Learned:** We started with ambitious plans to have four degrees of freedom in the manipulator, complex claw actuation, and many different pistons moving in different directions. We spent months and way too many hours talking and sketching and modeling a very complex design that was fundamentally flawed. One of the main components, a bearing, had been placed in a configuration that it could not support. In April we asked for a design review with experienced designers and they helped us understand how to choose the right bearings for the motion we wanted to support.

We researched solenoid valves for control, but they would have required a more complicated system, including an additional pressure vessel on the vehicle to hold the manifold & valves, and an electronic control system. Instead, we chose to do a mechanical control system (see pneumatic section). This was to reduce cost, reduce burden on the EE and CSE teams, and take advantage of contest regulations that limit electrical power to 48 volts but allow us to add a second energy source (40 psi of compressed air) to give us a higher total available energy to power ROV systems.

One of the first manipulator designs considered was a parallelogram configuration that would hold the two fingers parallel as they close. However, that design is more complicated, greatly increasing the time to manufacture and increasing the weight on the vehicle. We instead chose a simple rotating configuration with fewer moving parts that would be easier to enclose for safety. We designed two sets of fingers to help us carry out the tasks. The first was a simple set of angled fingers that overlap to accommodate shapes from 0.5" diameter to 8" across (below, right). This is the standard gripper that we use for most manipulation tasks. The second set of "fingers" designed is a sample collecting basket that would allow delicate samples to be scooped and returned to the surface without damage.

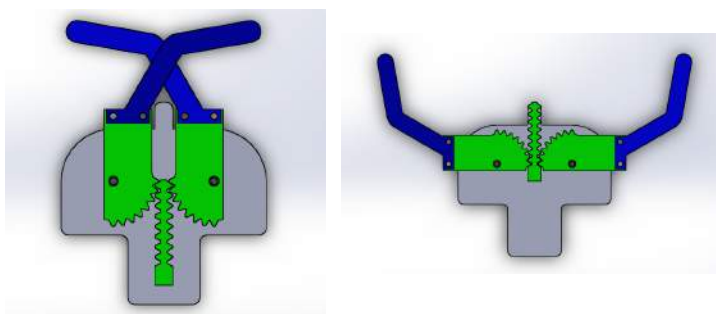

Figure 7. Manipulator design. Demonstrating the open (right) and closed (left) position.

Pneumatic System

The manipulator (the claw and rotation of the arm) and other tooling (such as the magnet and an impact wrench) operate by controlling pneumatic pistons via a mechanical control panel on the surface. Pneumatic pistons are a component of a fluid power system, or a mechanism that operated by manipulating the flow of pressurized fluids. If the fluid is a gas, then the system is a *pneumatic* system (from the Greek stem *pneum*- referring to air or gas as in *pneumothorax*) and relies on the expansion of compressed gas and is frequently seen in factory automation, and in medical and food processing equipment. If the system uses liquid as a fluid, then the system is a *hydraulic* one (from the Latin stem *hydr*- referring to water as in *hydrologic cycle*) and relies on the comparatively incompressible properties of liquids, as seen in forklifts, excavators, cranes and other construction and industrial equipment. Some systems incorporate both pressurized gas and pressurized liquid in a *hydropneumatic* system, as is commonly used in the State of Washington in plumbing meant to deliver drinking water. Using fluid power has several distinct advantages over electric counterparts that make it the best option for use on our ROV. First, all parts of the fluid power system are sealed for use with internal pressure, so they will work readily underwater and can handle the external pressure that occurs with shallow depths. Secondly, we can eliminate the need for linear actuators or servos that drain the batteries needed to run the motors and cameras of the ROV. The current pneumatic system is entirely mechanical and is operated independently from the rest of the ROV. Similarly, while transmitting electric power over long distances (as the long length of the ROV's umbilical) can cause a significant loss in voltage, pressurized fluid can be transmitted over long distances and through complex configurations with only a minimal loss of power.

For our uses, a pneumatic system presented the best option. Because air can be compressed easily, compressed air can be stored in a scuba tank and taken with the ROV wherever it operates. While operating a hydraulic system requires a continually running pump, mandating the use of either an electric outlet (which is not always available in locations where the ROV would operate, as on a beach), or an internal combustion engine. From a logistics standpoint, hydraulic pumps are very costly and would be difficult to ship, while renting a scuba tank can be done inexpensively in any major city in North America, making a pneumatic option the better choice for travel to St Johns. While using a tank gives us a finite supply of air, an 80 cubic foot tank lasts the team through an entire day of use and even a 13 cubic foot or 6 cubic foot pony bottle would suffice to run the vehicle for several hours of intensive use. Additionally, scuba tanks are filled with breathing-quality air, which is drier than typical air in the atmosphere, an attribute that can only be achieved with very expensive air compressors. Compressing moist air and allowing it to expand in the pistons on the ROV could cause water vapor to condense or even freeze in the pistons when the vehicle is in water colder than 32°F, as occurs under ice sheets in the Arctic. A pneumatic system can also offer features not possible or practical with a hydraulic system.

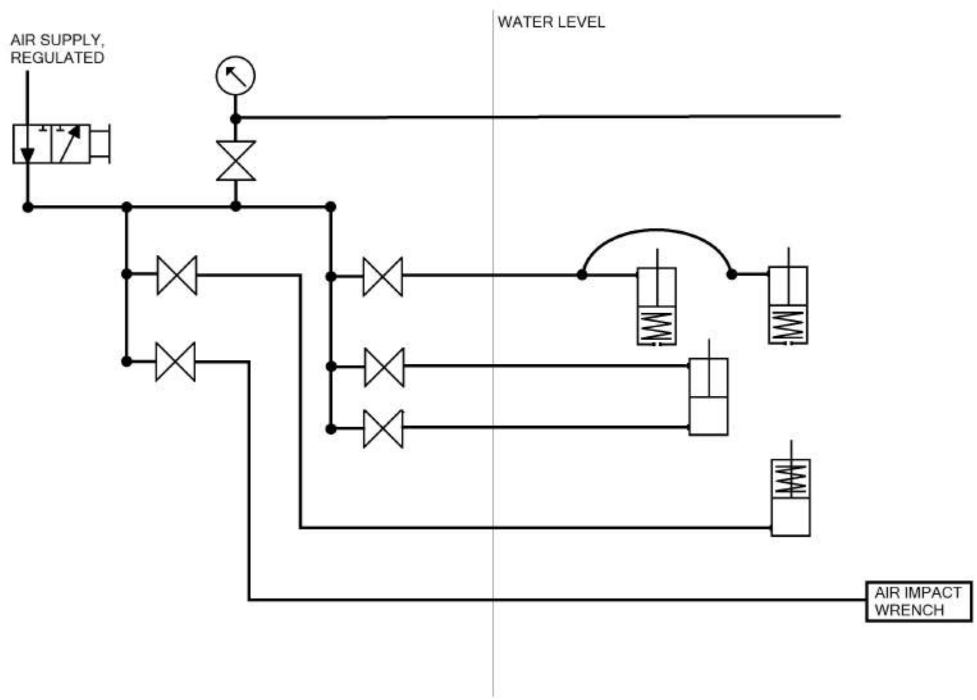

Figure 8. Pneumatics Systems Integration Diagram.

We can use a small air impact wrench to turn a valve underwater; by comparison hydraulic impact wrenches are larger, heavier and more expensive. We can also use pneumatics to measure depth using a *pneumofathometer,* a device commonly used in hard-hat diving that measures the pressure underwater by expelling air through an open tube. Venting air on the ROV also produces bubbles on the surface which can be used to locate the ROV when it is operating in a body of water with little current of surface swelling, as in lakes, providing an additional navigational aid. Air can also be used to fill lift bags underwater, and can be used to displace water in an active buoyancy system which can be added onto the vehicle later.

Operating the pneumatic system begins with regulating the pressure of the air source. A typical scuba tank is filled with air until the internal pressure is equal to 3000 psi (pounds per square inch). The release of the air is controlled by a valve on the top of the tank. Air comes out of this valve at whatever pressure is contained within the tank, and as air is released the pressure in the tank decreases, draining the tank. Regulating the pressure from the tank is done by two regulators. First, a first-stage scuba regulator regulates the tank pressure and sends it to several low-pressure ports, one of which is connected to tubing which goes to the control panel. Tank pressure is measured using a valve on a swivel connecter attached to the high pressure port. We are currently using an Oceanic® Delta, which regulates pressure from the low pressure ports to 145 psi. Once at the control panel, air pressure is regulated by a second regulator to the 40 psi allowed by MATE for the competition. We use a Parker-Hannifin regulator which uses a locking ring to prevent accidental turning of the handle and changing the pressure. The regulated pressure is measured by a digital gauge which reads in 0.5 psi increments. Next a toggle-switch operates a two-position three-way valve, either filling the manifold with compressed air or venting air out of the manifold. Five needle valves control pressure to up to five lines going to the vehicle for use with tools, with a sixth valve being used to operate the pnuemofathometer. Needle valves either open or close a port on the manifold, but they can also control air flow, allowing the operator to control the speed at which the pistons move (for example, we can close or open the claw very slowly or very quickly, which is useful because rapid movements cause turbulence in the water, which can interfere with delicate operations; when dropping wellhead cover and gasket onto the wellhead, we close the needle valve most of the way to reduce airflow and slowly release the claw for this reason). Needle valves also allow the operator to add or vent small quantities of air from each side of the double-acting piston, which gives the operator enough control to extend the piston rod in multiple positions and is the reason why the arm is capable of rotating a full semicircle in small increments. The double-acting piston requires two air lines and different pressures in each line to extend the rod in different positions. This precision is necessary for tasks such as inserting the hot stab into the wellhead at a 45 degree angle, which requires the arm to rotate within a few degrees of a 45 degree angle. Equally importantly, once the dual-acting piston is adjusted to the desired position, the force applied to both sides of the piston will be held constant. This mechanical precision is a precision that was unmatched by electronic means of controlling pneumatic systems until very recently. Incorporating the non-linear nature of air compression into algorithms for electronic control systems has allowed pneumatic positioning to match that of hydraulic and electric positioning, a feat only developed in the last few years, and still far more difficult to incorporate in the ROV than the effort is worth.

Power System

After selecting our motor drivers and communication equipment, we devised a power system that optimized the use of space and conversion efficiency. The ROV is externally powered by the required 48 VDC at the surface. From there, we need 360 W of 12 V power to drive the motors and smaller amounts of 3.3 V and 5 V power to supply our communication system. After researching various types and sizes of 48/12 VDC converters we found that the Vicor DC/DC converters, which use a switching converter technology, produce a clean 12 V output with high efficiency. These converters are designed for low noise applications, which is helpful in a 3-phase motor system to prevent transient-caused vibrating and shaking. Each 12 V Vicor is rated for 120 W, so we used three in order to power our six motors.

Deciding on the connection of our six motors and three power converters, we decided to use two motors per converter, with the vertical motors assigned to separate converters. This system allows the vehicle to be retrieved in the event of a single converter failure, as well as a specialized control scheme that can dedicate maximum power to each vertical converter for quick vertical movement. In deeper waters where most of the travel is vertical, this feature saves time and increases reliability.

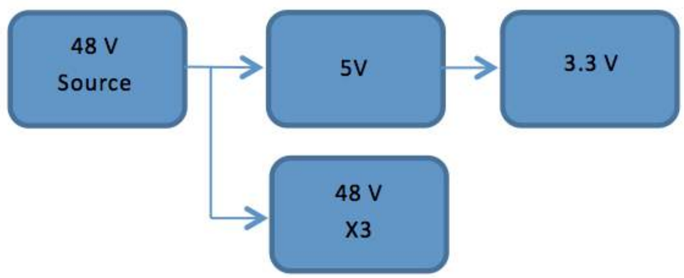

Figure 9.
Power conversion in the ROV

Following the lessons from last year's ROV, we used opto-isolators to electrically isolate the Arduino from the motor drivers. This protects the fragile digital chip in the Arduino from transient voltages produced by the motors. The opto-isolators are cheap and compact, ideal for our use in the crowded control housing.

To power the smaller devices used for communication we employed a similar Vicor DC/DC converter from 48 V to 5 V, and then a 3.3 V linear regulator drawing from the Vicor converter. All of our power needs were then met, with additional capacity in the 48/5 V Vicor converter for LED lights that were added after the regional competition.

Underwater Control System

The main purpose of the control system on the ROV is to set motor values and send back sensor values. Few calculations take place to increase running speed. Whenever the surface system sends bytes, they are read by the ROV. If the values are well formed, the motors are set to the appropriate values. Ten times a second, the sensor readings are sent back up to the surface. If there are no motor values for more than a second, the ROV assumes that connection has been lost and shuts off the motors for safety.

Motor Control

Changing the power or direction too quickly on the motors can have detrimental effects. To mitigate this, the Arduino on the ROV tracks the current output of the motors and does not let their value change too rapidly. This is done by saving the desired motor power (received from the surface) separately from the actual motor power. Periodically, the actual power is updated in the direction of the desired power by an amount proportional to their difference.

Communication

The communication system in the ROV is designed for a tether up to 78 m, which introduces a number of challenges. With six motors to control and two cameras to stream, a lot of bandwidth is needed in our tether. First, we had to rethink the camera connection, which is limited in length by the technology used. Our previous design used individual cables for each camera from the surface, but they are not commonly made for longer distances due to signal degradation. We decided an entirely digital system with a single communication line to the surface would simplify and lengthen our tether. Our solution to transmit the data over long distances is to repurpose a Tenda Ethernet-over-powerline device commonly used to connect faraway rooms in a house to the internet. These devices provide a robust signal that can travel up to 91 m with a sufficient 50 Mb/s of bandwidth. To use the Ethernet converter we first need to encode the USB signal to Ethernet with software, which was then sent to the Tenda to be converted and transmitted through the length of the tether. At the ROV, another Tenda decodes the signal to Ethernet, where the signal is finally converted back to USB in a Silex Device Server. The full process is shown in Figure 10.

Communication system from the surface to the ROV

Figure 10.

The motor drivers are controlled by pulse width modulation (PWM), requiring an Arduino or similar digital board. We went with an Arduino Mega 2560 for its many PWM ports and the company's familiarity with Arduino coding. The Arduino communicates through USB and is plugged into our device server, as are both cameras.

Communication between the Arduinos and the computer occurs by sending very small, five byte packets very rapidly. Each packet consists of a two byte header followed by some values. The header is a simple and easy way of ensuring integrity of the system: it prevents random bytes from being read and makes sure that headers are not interpreted as data, or vice versa. The other three bytes specify what the packet should be used for. This can either be setting motor values, or other special functions such as flashing the onboard LED for testing purposes.

When reading values, each system (the computer and ROV) looks for a valid header. When it finds one, it knows that it has found a valid packet, and processes it. It then waits until there are enough bytes waiting (at least one packet's worth), and repeats the process.

The USB communication with our cameras and Arduino requires multiple serial data conversion steps in order to send data across the length of the tether. Since the stability of our system relies heavily on each of these devices, we decided to use existing commercial products like the Tenda P200 and Silex Device Server for their reliability and ease of use.

Programming

There are two main components that comprise the drive system: a surface side computer in the control box and an Arduino microcontroller that drives the ROV itself. The computer controls the GUI, displays sensor values, and sends joystick values and other commands to the ROV while the remote Arduino receives drive values and sets the motor power accordingly, as well as sends sensor data back to the surface.

This year, the code is written in Python 2.7 for surface control and C++ for the Arduinos. Python was chosen for its ease of use and portability to various different systems, and version 2.7 is the most widespread and supported stable release. We also used libraries available so that we could easily display the GUI. C++ was the best choice for the Arduinos as it is widely supported and is fast enough that programs can run efficiently.

Surface Control

On the surface, the GUI offers a bridge between the pilots and the ROV. It is designed to be intuitive and practical, and runs off a computer stationed in the control box. The interface is written in Python 2.7 and makes use of the Pygame module for hardware interfaces and graphics, and the pySerial module for communication with the Arduino.

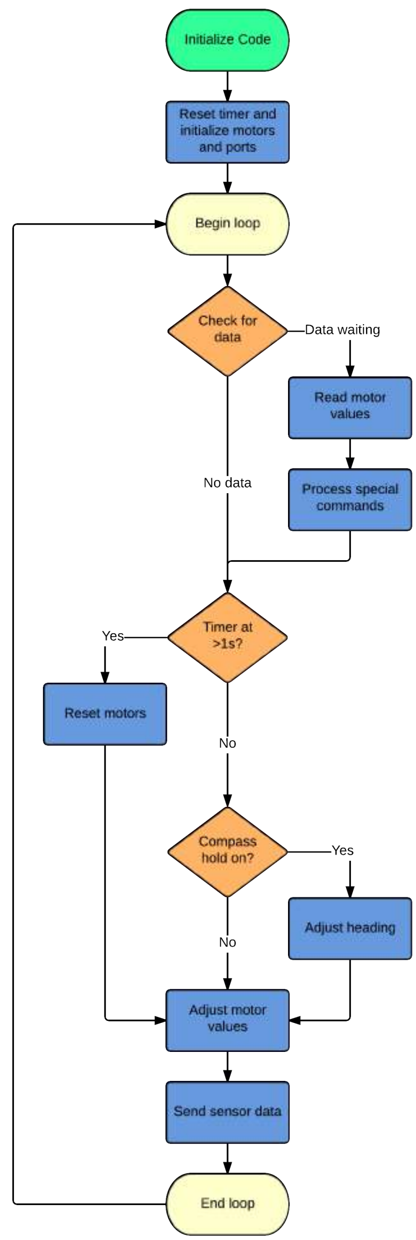

Figure 11. Arduino Flowchart.

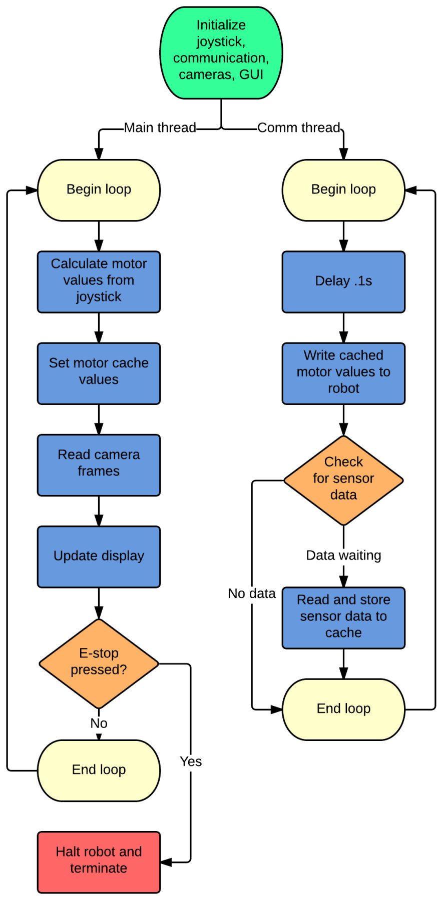

Figure 12. Surface System Flowchart.

Hardware

To control the robot's motion, an Xbox controller was used. A wired version was chosen because wireless versions we have used in the past sometimes lose connection at inconvenient times. However, any controller would work, and we could still use wireless versions for testing the robot so that the driver was not tethered to the control system. The Xbox controller itself is an easily understood interface that many are familiar with and it includes the axes and buttons that are required.

Motion Calculations

The surface computer receives joystick and other input and calculates the appropriate motor outputs. Vertical motion is simple, as there are only two motors that exclusively control it, but horizontal motion is more complex due to the angled motor configuration.

To do this, we first translated the joystick position into a point in 2D space, and multiplied by a matrix so that it is represented in a basis that has axes parallel to the motors, at 45 degrees from the original Y-axis. The power for each motor is then the coordinates of this point in the new basis, normalized so that the motors do not run at more than 100%. Turning is considered a separate axis, and the motor rotational value is scaled linearly with the joystick axis that designates rotation. To find the overall horizontal motor power, the translational and rotational components are calculated, in the range -255 to 255, and are then summed and capped at the max value. As negative values correspond to running the motor backwards, summing the motor powers is an effective means of combining translational and rotational motion.

Once the motor values are calculated, they are sent to the Arduino. Usually, the Arduino just sets the motor values to the read values. However, we have a compass on the robot, and can use this to track our position and align to a given angle, even in a noisy environment. To do this, the Arduino calculates the offset between its current heading and desired heading, and adds a rotation component to its motion that scales with the offset. This calculation is not sent to the surface to reduce the latency. After the rotation is applied, the values are again scaled so that the motors do not exceed their maximum speed.

Motion Stabilization

We also have means of stabilizing the robot programmatically. Because water densities and the exact ROV configuration differ from place to place, making the ROV neutrally buoyant everywhere is difficult without the time consuming task of adding or removing increasingly small weights. To circumvent this, there is a feature by which the pilot can set the vertical motors to add a constant force, either upward or downward, to their usual motion to simulate weight being added or removed. If the ROV is too light, there will be a constant downward force; if it is too heavy, there will be a constant upward force. This allows the pilot to focus on completing the tasks rather than have to worry about keeping the vehicle from rising or sinking.

As mentioned before, we also have a compass on the robot that we can use to keep a specified heading. This allows the driver to worry less about which direction the robot is pointing and focus instead on moving it to the correct position.

Safety

Electric Safety Measures

1. Fuse and circuit breaker prevent damage from shorting or overdrawing our power supply.
2. All cable splices are heat-shrinked to insulate exposed wire.

Safety Checklist

1. Ensure all sensitive electronic equipment is dry and there is no noticeable damage to the tether.
2. Check the 30A fuse on the 48 V supply connector and ensure the tether power is switched off.
3. With ROV out of water, check that all connectors are tight and the vacuum seals are in all housings.
4. Check O-ring seals and thruster props for damage.
5. Plug in the surface system, including the computer and tether box 120 V wall adapter.
6. Attach the tether to the surface system and ROV, including strain relief. Make sure connections are screwed tight.
7. Switch on power to the tether, immediately checking the ROV for normal operating lights on the motor drivers, Arduino, and LED lights in the camera housings.
8. After a few seconds with power, check that the three green LEDs on both Tenda boards (surface side and ROV) are lit. A flashing middle light indicates data is being transmitted while outer lights indicate power.
9. Start SX device server software and virtually connect both cameras and the Arduino.
10. Check that the camera images are updating and each motor is working.
11. The ROV is now ready for deployment.

Pneumatic Safety Checklist

1. The single point to shut down and turn on the system is the valve on the scuba tank.
2. Before opening the tank valve, be sure that the ROV is clear and all valves in the control box are shut off and the regulator is regulated down completely. (The regulator provides an accurate reading only when the pressure is being raised.)
3. Turn on the digital pressure gauge and slowly turn on the tank valve. Adjust the regulator to the desired pressure, which is under 40 psi per MATE standards. Push down the ring around the regulator to lock its rotation, preventing an accidental change in pressure. All components are designed for a working pressure of at least 150 psi, and the low pressure ports on the first-stage regulator (the regulator attached directly to the valve of the tank) regulates air to a maximum of 145 psi, to prevent the system from being over pressurized should the manual regulator be improperly set.
4. The vehicle is now ready for operation by needle valves and toggle switch.
5. To depressurize the system when the vehicle has finished its operations or in case of emergency, start by closing the valve on the tank, thus shutting off the compressed air supply. There may be pressurized air in the lines and manifold, so to vent all lines and the manifold all other valves should be opened.
6. Verify that pressurized air is vented from the system by looking at the gauge on the high-pressure port of the regulator, which should read "0 psi". The first stage regulator can now be taken off of the tank and control box packed up.

Mechanical Safety Checklist:

1. All hardware must be secure: check bolts, nuts, mounting bars, hinges, brackets, tether clips, cable management.
2. Gears are a potential crush danger for fingers, tools, or stray lines. Check that everyone and everything is clear and safely constrained outside of gear operating areas.
3. All gears must be properly aligned, non-binding, held within their safety guards.
4. All bearings and pistons must be moving freely and clear of obstruction.
5. Check that all bolt tail covers are in place, all warning signs in place.

Figure 13. A member of UWROV wearing safety glasses while working on Admare.

Electronics Testing

After designing the system, each component had to be thoroughly tested and understood before it was allowed to become part of the vehicle. Starting with the power converters, we plugged each 48/12 V converter into a 48 V supply and measured the output under an open load. Then, we ran them with previously tested motors to ensure a clean output under heavy load. The Vicor converters overheated when run at maximum power without a heatsink, so we installed them directly to the endcaps in order to quickly dissipate heat to the surrounding body of water. We ran the mounted converters in both water and air and found them to be much more thermally stable.

The motors require an Arduino, ESC motor driver, and power converter in order to be tested. By powering the Arduino through USB and uploading a sample code given to us by Blue Robotic. Of the six motors, one did not work at all and another screeched when run on the table. Running them in water fixed the noisy motor but we had to send in for one replacement motor.

To test the power converters and measure motor power consumption we connected two motors a single 10 A Vicor 12 V converter and measured a single motor's current.

Power level	Amps
50%	2.2
75%	5.0
100%	6.2

At 75% power we are maxing out the DC converters, and at 75% power the ESCs heat up after a few minutes. With this information we set the absolute maximum power to 65%. Further testing ensured the ESCs could handle 65% for long durations, as indicated by their nominal limit of 30 A.

Figure 14. The Electrical Engineering team working out in Portage Bay, testing Admare's systems.

We encountered a problem with our motor drivers when the opto-isolators were installed in the signal chain. After confirming that each motor driver worked without the isolators, we measured the input and output PWM going through the opto-isolator with an oscilloscope. It turned out the isolators were stretching the pulse by a few microseconds, just enough for the motor drivers to misinterpret the startup signal sent by the Arduino and thereby locking up the motors. By changing the code and shortening the pulse by a small constant, the motors worked with the opto-isolators.

The initial power system design used chip-sized switch converters to drop 48 V to 3.3 V and 5 V. Each chip also required an inductor, capacitors, and a diode in order to operate, all of which had to be soldered onto a board for the converter to function. Initial tests showed that the converters were hard to make compact with the recommended inductors. We tried using undersized inductors, but overheating and output ripple were inevitable. Finally, we reimagined our conversion process by using a reliable Vicor 48/5 switch converter and linear regulator from 5 V to 3.3 V. This approach gave us clean DC power at each voltage and was almost as efficient as the original switch converters.

Scheduling

At the beginning of the year UWROV came up with a schedule that was advantageous. It became known as the schedule of good intentions. Meaning, the team soon fell behind and could never fully recover. The schedule was meant to help alleviate the stress at the end of the year, but too much time was spent on brainstorming and sketching the critical systems for Admare. Next year a more reasonable schedule is planned to be created and multiple projects will be worked on at the same time unlike this year where each team mainly focused on one project at the same time. This change is made possible by the fact that the team is rapidly growing (the team tripled from last year).

Reflections

As with all major projects there are a lot of experiences in which to reflect upon. The team is three times larger this year and with such a growth, new obstacles must be overcome. Thankfully with the increase in the amount of members on the team, we could become more specialized in various fields, allowing us to understand specialties in greater detail. More ambition systems could be approached with more collaboration and knowledge between students. While we were broken up into more specialized groups, our company remained small enough that we could still interact with one another effectively.

This effective interaction was proved useful when approaching professional businesses in order to obtain donations, resources, and knowledge that was used in the construction of our vehicle and marketing of our club. Returning team members shared their sales presentation skills with the team and utilized that knowledge in developing presentations for potential donors.

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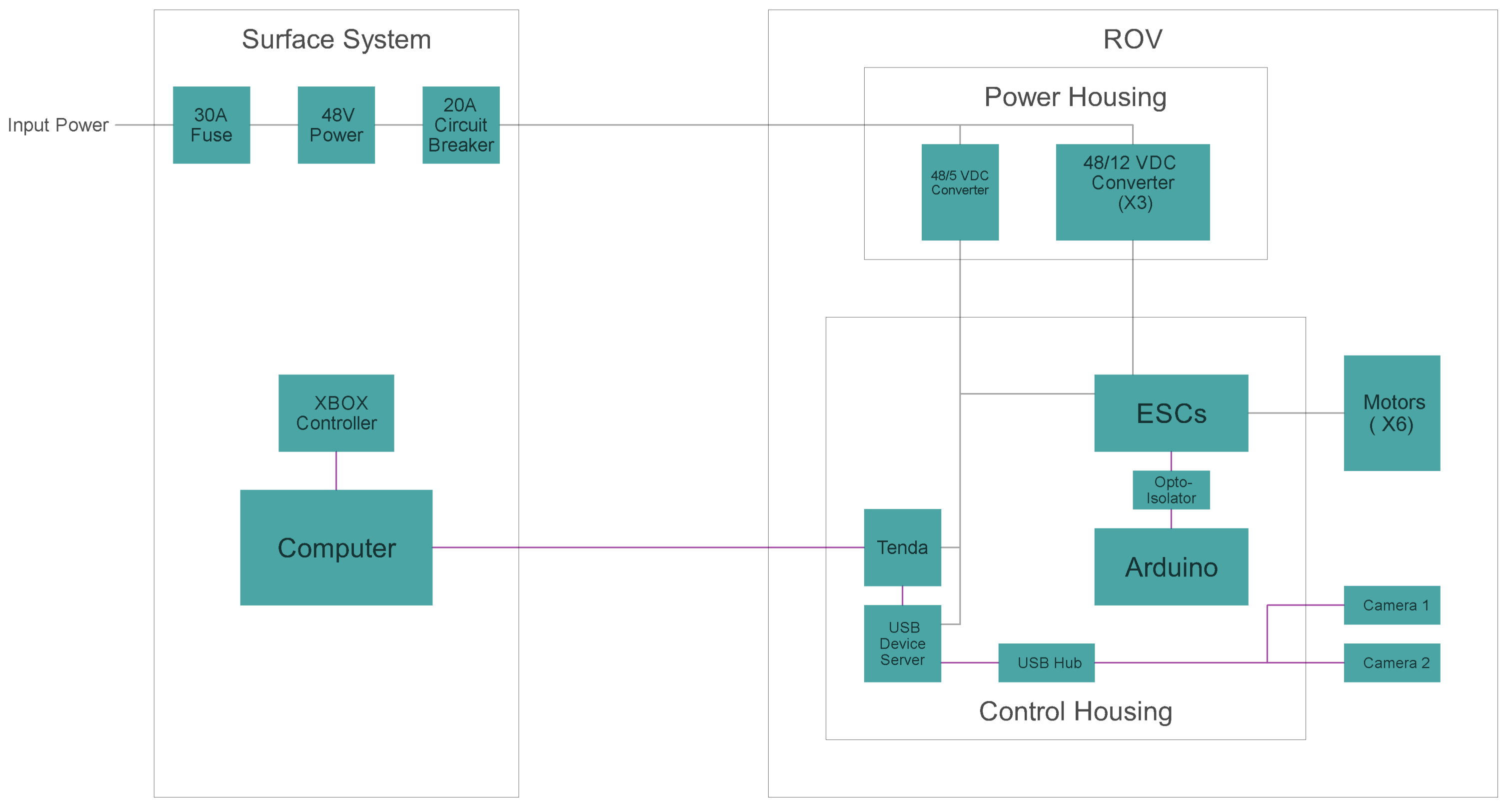
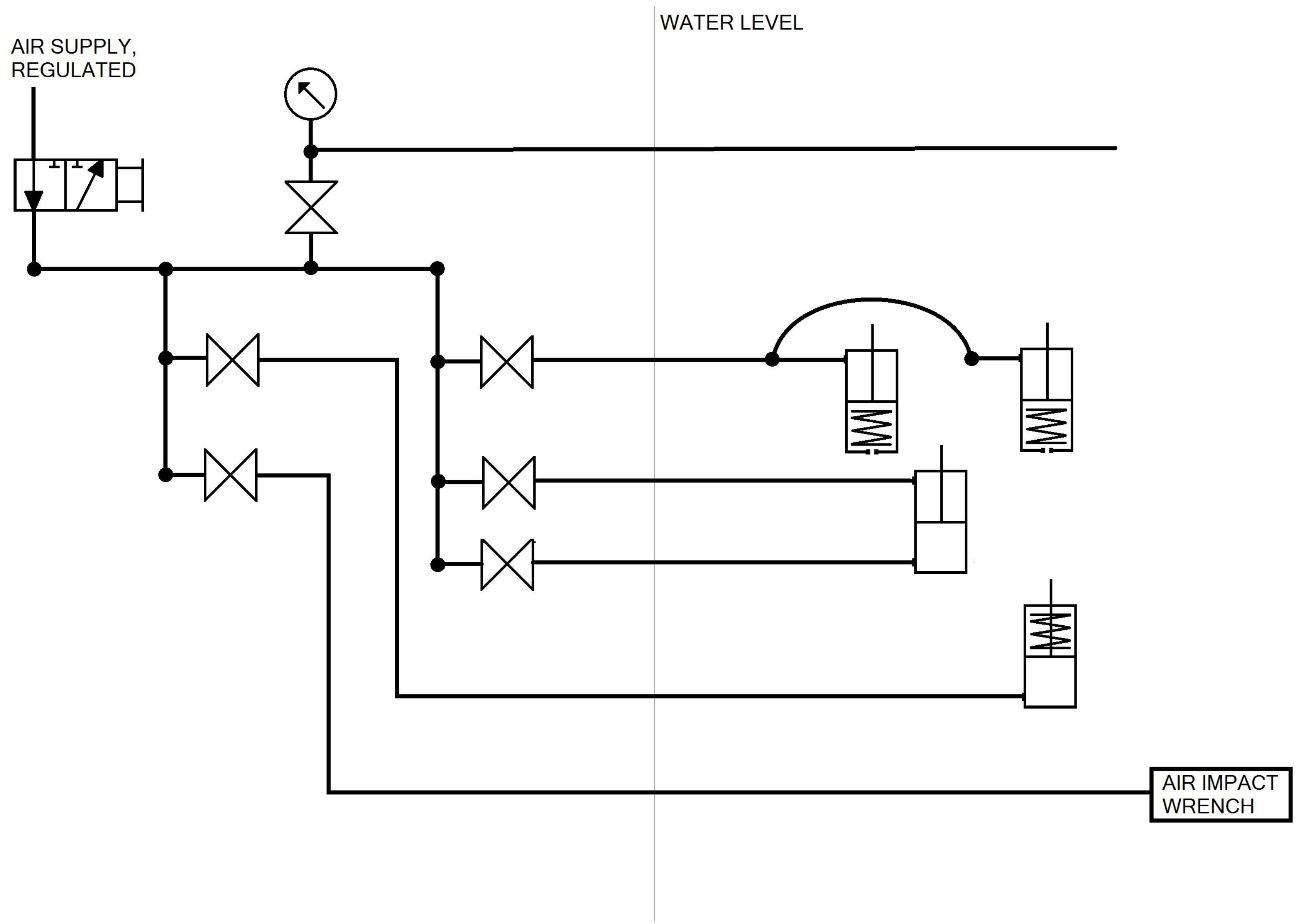

Surface System
Input Power
30A Fuse
48V Power
20A Circuit Breaker
XBOX Controller
Computer
ROV
Power Housing
48/5 VDC Converter
48/12 VDC Converter (X3)
ESCs
Motors (X6)
Opto-Isolator
Arduino
Tenda
USB Device Server
USB Hub
Camera 1
Camera 2
Control Housing


AIR SUPPLY,
REGULATED
WATER LEVEL
AIR IMPACT
WRENCH