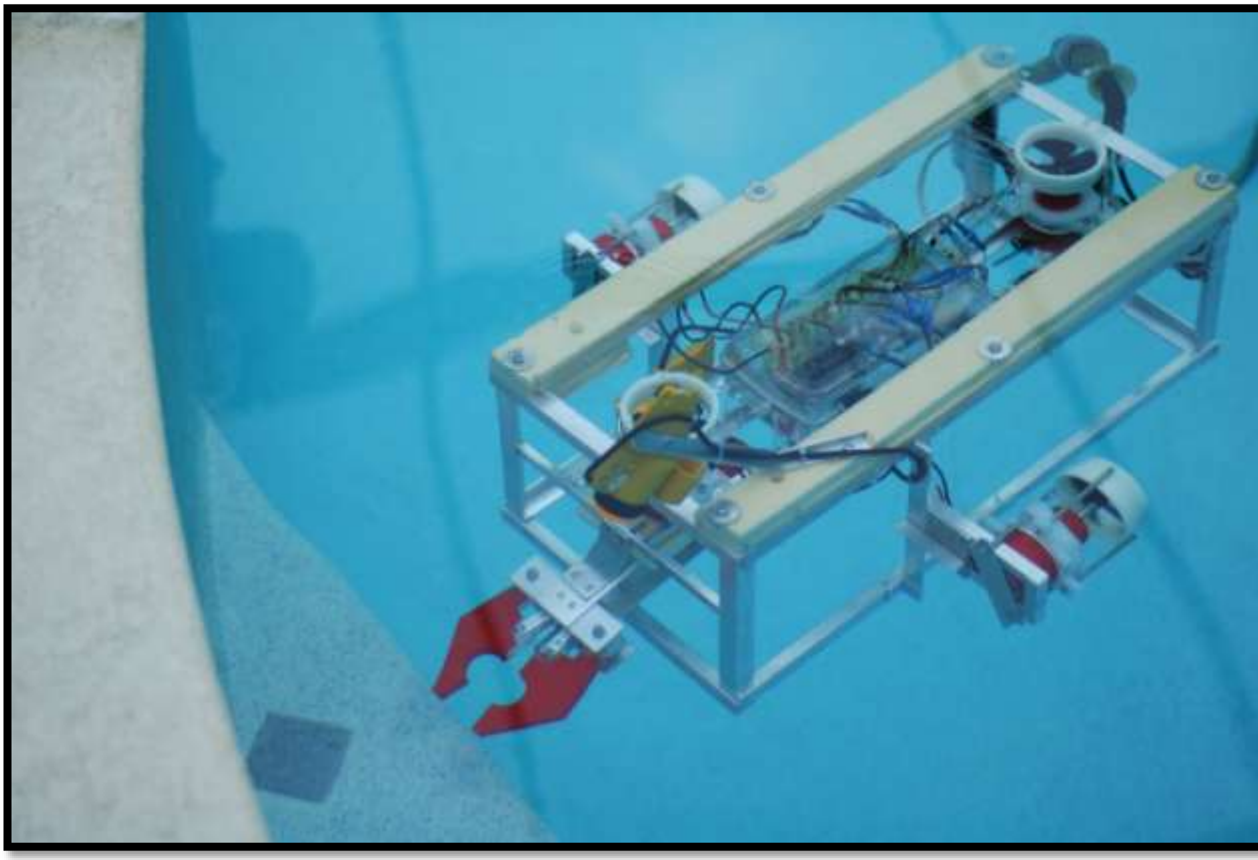
Tachyon Robotics

Seminole High School – The Geneva School
Orlando FL, USA



The completed Tachyon Mk. III

Company Members (from left to right):

Sam Knight- CFO, Pilot, Programmer

Evan Terry- Tether Manager, Engineer

Kieran Wilson- CEO, Chief Mechanical Engineer

Michael Ikegami- COO, Chief Electrical Engineer

Mentor:

Mr. Joe Wise

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Abstract

Tachyon Robotics is a full-service ROV design and fabrication company, dedicated to developing and building the fastest, most maneuverable and cost-effective robots available since 2009. Our company harnesses our employees' deep engineering expertise and experience in building high-quality, reliable, digital control systems, manipulators, and pressure housings.

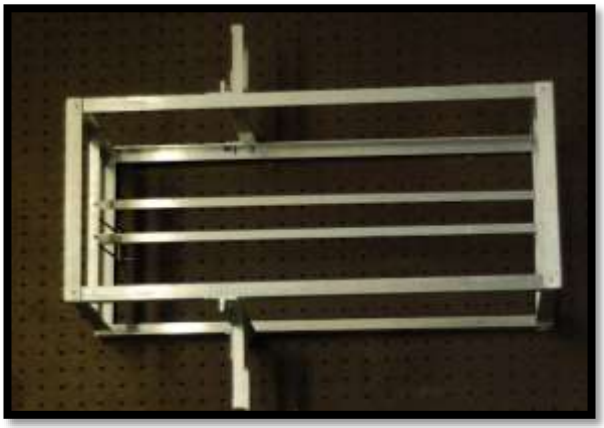
We recognize that our robots must not only surpass our customers' standards, but must also be cost effectively constructed to maximize the return on our customers' investment. To reduce costs and improve quality, we design and fabricate many components in-house rather than purchase more expensive commercial equivalents, including motor controllers, circuit boards, and thrusters.

Tachyon Mk. III is designed to demonstrate our company's ability to contend with the challenging conditions of the unstable WWII era shipwreck the *MS Gardner*. Our pilot is trained to use the ROV to survey the wreck site and then proceed to clear the hull of any obstructions, including endangered corals and the broken mast. Once the hull is clear, we will drill into the fuel tank and remove the remaining oil before resealing the tank. To accomplish these tasks, we constructed a light-weight, low drag ROV with features including a manipulator and oil sampler integrated into a compact aluminum frame. The robot is powered by four modified bilge pumps outfitted with propellers and custom nozzles and utilizes a digital control system that incorporates an Xbox 360 controller, a laptop, an Arduino microcontroller, and custom-built motor control boards.

Design Rationale:

Frame and buoyancy

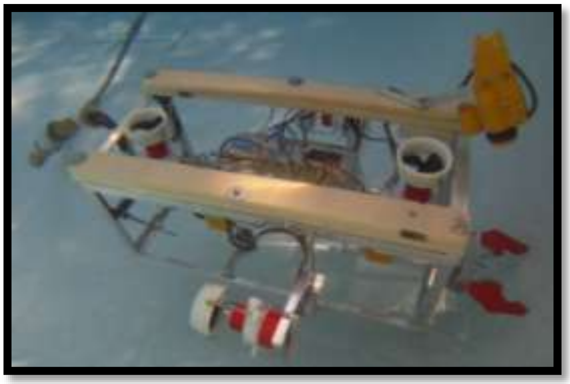
Previously, Tachyon Robotics used PVC as a frame material; however, in spite of being easy to machine, PVC was less than ideal for the frame. When a PVC frame fills with water, the robot must move not only its dry mass, but also the mass of the water in the frame, which we calculated to be approximately 3 kg in Tachyon Mk. I. For a robot with a mass of only 5.5 kilograms, this is a significant increase in mass which dramatically slows down the ROV. Therefore, we decided to move from PVC to a frame made out of 3/4" and 1/2" T-6061 angle aluminum. Because of the difficulty of producing anything but right-angled joints using angle aluminum, the frame was designed around a basic box shape, with joints riveted together for maximum strength.



Tachyon Mk. III's aluminum frame.

Tachyon Robotics wanted to minimize the size of the ROV to reduce its drag, but also wanted maximize the distance from the center of mass of the ROV to the thrusters, in order to maximize the rotational force exerted on the robot by the motors and to allow the ROV to turn more easily. Therefore, we created small struts, which stick out 10 cm from the side of the ROV. This increased their distance from the center of the ROV to the motors and enhanced the ROV's maneuverability.

To maximize the effectiveness of the ROV, it must be neutrally buoyant, which means that it has the same average density as the water. If an ROV is not neutrally buoyant, it will have trouble moving vertically through the water, slowing it down. Most components on the ROV are negatively buoyant, so they have a tendency to drag the ROV down. To rectify this issue, we used a marine-grade incompressible foam (Corecell A400). This foam has a relatively low density of 69 grams per liter [1]. The pressure housing also displaces a significant amount of water and reduces the amount of foam needed to make the ROV neutrally buoyant. Using carefully proportioned amounts of foam brought the ROV’s overall density to that of water.



The two pale yellow strips running the length of the ROV are Corecell A400 foam, used to provide buoyancy.

This foam does not compress with depth or become waterlogged, thus keeping Tachyon Mk. III's buoyancy constant even when the ROV is in the water for extended periods of time. We decided to place the foam along the top of the ROV to keep the center of gravity as high as possible, which reduces rolling. This design feature gives the ROV a strong righting moment, keeping it oriented upward correctly. However, we discovered that the two broad sheets we had placed over the left and right sides of the ROV generated too much drag when trying to move vertically. Instead we formed two multilayered strips of foam that run the length of the ROV, providing correct buoyancy with minimal drag.

Control System

Our current control system represents one of the greatest innovations in our robot since Tachyon Robotics first began producing ROVs in the summer of 2009. Our first ROV, Tachyon Mk. I., utilized an analog control system with "tank-style steering." Although it presented a certain degree of reliability that is difficult to replicate with a digital system, it offered only very limited maneuverability.

Therefore, in order to complete our mission tasks as efficiently as possible, Tachyon Robotics decided to implement a digitally based control system. This control system allows the ROV's operators (pilots) to interface easily with the robot through a medium most teenager are familiar with—an Xbox 360 controller.

The implementation of a digital control system necessitated a switch from passive electronic components (such as switches and rheostats) to active components (such as transistors), which can more easily interface with a computer.

Tachyon Robotics researched the possibility of purchasing pre-manufactured circuitry to interface with our microcontroller (an Arduino microcontroller that, in turn, interfaces with our ROV's computer), but decided against this option because of the price (see cost analysis in Table 1 to the right), and because fabricating circuitry in-house presented an enormous learning opportunity.

As a result, Tachyon Robotics' electrical engineer, Michael Ikegami, spent a great deal of time researching circuitry development as well as basic transistor electronics. After months of work, the team finally developed a circuit that effectively controlled the direction and speed of each motor, as well as any peripheral devices.

Table 1: Cost comparison of commercial and Tachyon Robotics in-house motor controllers

	Cost of Single Unit	Cost of System
"Off the Shelf" motor controllers	$31.95	$161.70
Motor control Circuitry manufactured by Tachyon Robotics.	$8.86	$53.16

A two-layer CAD drawing of the circuit board located in our pressure housing. This circuit controls the bulk of the ROV's movement. This drawing was transferred to copper clad board to produce our printed circuit boards.

A cost analysis between standard "off the shelf" motor controllers and the circuitry created by Tachyon Robotics. The low cost of developing the circuitry allowed Tachyon Robotics to create duplicates of all circuit boards while staying within our budget.

The circuits were designed through printed circuit board CAD software, and created using the "toner-transfer" method. Using this method, Tachyon Robotics printed, transferred, and etched the traces of each circuit onto a piece of copper clad. Then holes were drilled in each circuit board and discrete electronic components were soldered in.

The basic control system for each motor or motor group consists of a double-pole double-throw relay to control direction, with its output "sinked" to an IRF3205 metal-oxide field effect transistor. This transistor is controlled by an Arduino microcontroller that produces a 100Hz Pulse Width Modulation signal. In order to prevent any malfunction in the control circuitry from affecting sensitive electronic devices, such as the laptop or microcontroller, Tachyon Robotics isolate the control system electrically. This isolation was done by using optical isolators, which replace the electrical connection between our Arduino and our circuitry with an infrared light emitting diode and a phototransistor.

The top side electrical systems mounted in the waterproof Pelican case.

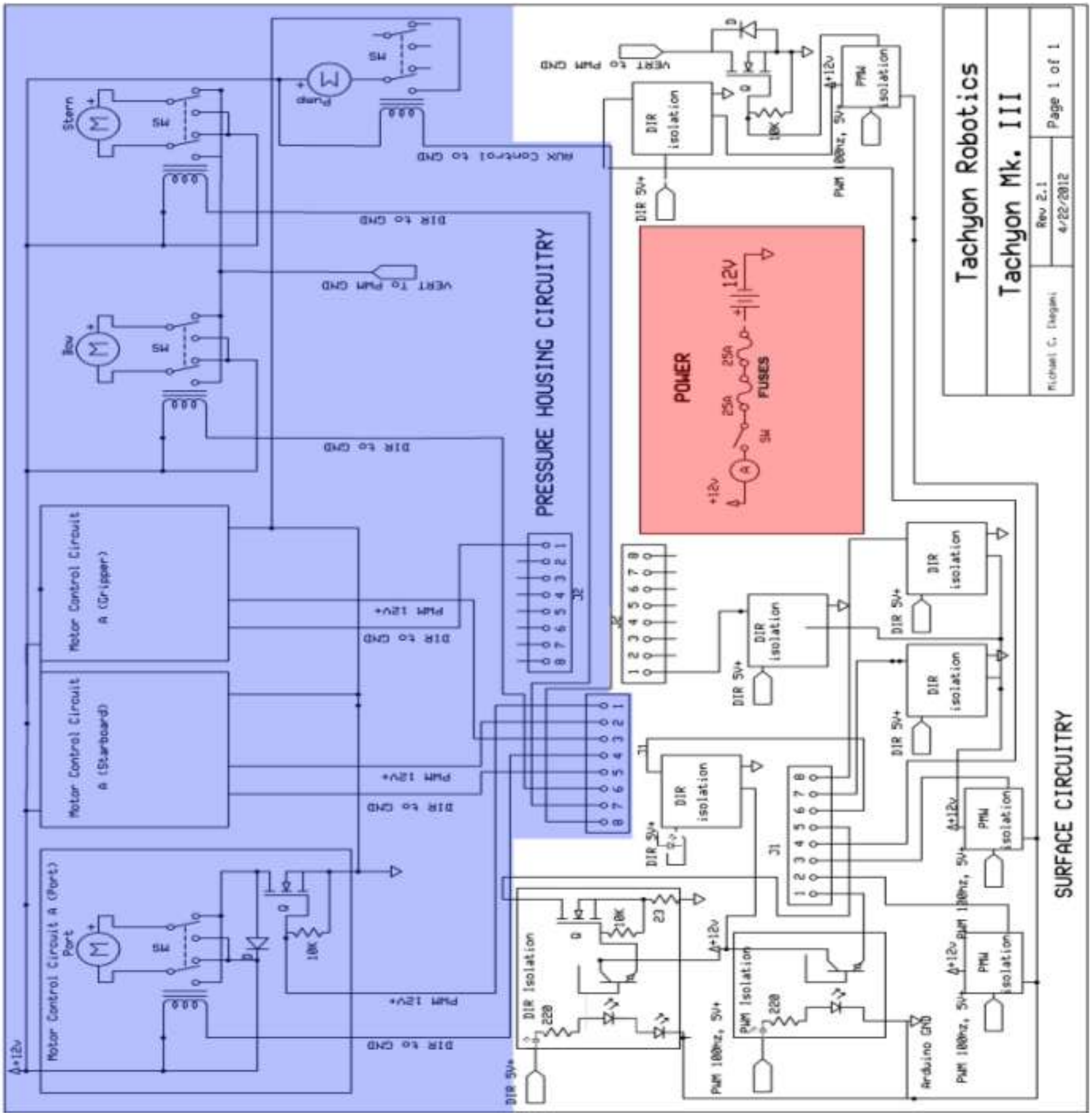
This year, our team worked hard to minimize the area of our circuitry, and to maximize the functionality it provides. To do so, the circuitry was designed to control both individual motors and motor groups. For instance, our horizontal thrusters were each controlled using separate H-Bridge circuits. This schematic allowed our pilot to have a fine degree of rotational control, as well as the ability to trim motors. The vertical thrusters, however, were controlled as a motor group; each motor had the ability to change direction, but the speed of the motors was not individually controlled. Instead, a transistor controlled both motors. This allowed us to save significant space on the circuit board located in our pressure housing, while giving our pilot maximum controllability.

Tachyon Robotics also had to overcome an obstacle associated with pulse with modulation. On our robot for the 2011 season, Tachyon Mk. II., our team had achieved a significant increase in maneuverability as a result of the implementation of a digital control system, but our throttling capabilities were limited. Furthermore, our team noticed that the speed controlling transistors were reaching temperatures far higher than what we expected.

In order to investigate and resolve this problem, we had to use an oscilloscope, a tool that displays a graph of voltage in respect to time. Through analyzing the nature of the waves at the gate of each transistor, we were able to determine that a resistor value in our circuitry was increasing the time constant of the gate of the transistor, causing our transistors to turn off more slowly than desired. After swapping out the resistor, we were able to obtain full potentiation of our motors, giving our pilot pinpoint accuracy when maneuvering the ROV.

With this improvement, as well as the overall improvement offered by a digital system, Tachyon Robotics was able to produce a robot that is natural to control and performs the mission tasks as efficiently and effectively possible.

Electrical schematic



This is the electrical schematic for Tachyon Mk. III. The blue section denotes circuitry that is submerged in our pressure housing, the white section notates circuitry located on the surface, and the red section reflects Tachyon Mk. III's connection to its power supply. Special attention was paid to maintain safety in this configuration—Tachyon Robotics utilizes two fuses (one of which is provided by the MATE organization), an ammeter, physical disconnects, and a switch to prevent short circuits and other dangerous malfunctions.

Software Discussion

Tachyon Mk. III's control system relies on two programs running on different systems to function: the first one runs on a Windows-based laptop, while the second program runs on an Arduino Mega microcontroller.

The computer acts as an interface between an Xbox 360 controller used by the pilot and an Arduino Mega microcontroller that controls the ROV's circuit boards. The computer's program was written in C# and uses the SlimDX library as an interface to poll the Xbox 360 controller. This program makes use of multithreading to prevent particular subroutines from slowing down the whole program loop.

When the program on the computer starts, it loads forms and a control system scematic from the hard drive and connects to the Xbox 360 controller and the Arduino. Both the Arduino and the Xbox controller are connected to the computer via USB. If any of the attempts to connect fail at initialization, the program will start normally and tell the user which components are missing. The program is functional only when both of the components are correctly connected.

The program on the computer constantly checks the Xbox controller for changes. When the pilot provides input through the Xbox that signals a motor state to change, the program's motor objects recalculate and send the new data to the Arduino Mega via a USB connection.

The program was designed to be general pupose, so that an engineer can add, remove, or change motor objects in a list at runtime without a need to restart the program or recompile the code. Each motor object represents a controllable motor or motor group. Additionally, controller mappings are individually assigned to each motor object so that the user can change how the Xbox controller affects each of the motors independently. Before the program closes, it automatically saves its configuration so that all of the settings and changes are still available the next time it is used. Because the program is general purpose, Tachyon Robotics can quickly redeploy this same software for any of its future ROVs, without the need to redesign or even recompile the software.

The program on the Arduino Mega was written in C/C++ through the Arduino Environment. This program's purpose is to read data sent by the computer's program from the USB serial port and execute the instructions, then send control signals to the ROV's circuitry. The majority of instructions sent during active operation are for updating digital and PWM pins, which in turn send signals to the above-water isolation and amplification circuitry, in preperation for controlling motors on the ROV. The program was designed and optimized to run efficiently in order to avoid bottlenecking the entire system and introducing lag.

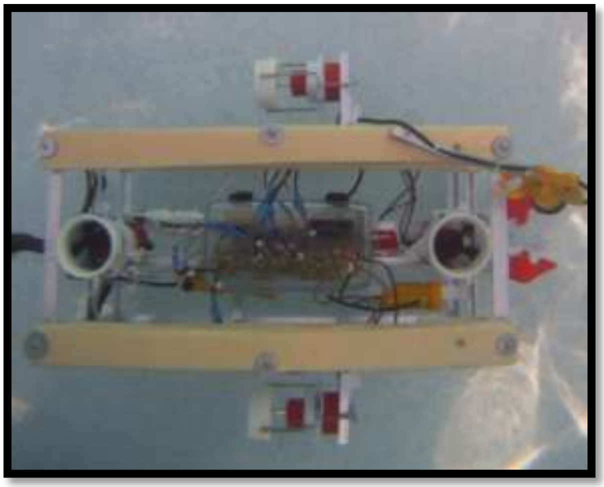
A fail-safe feature was added to protect the ROV and anyone in the water near it if the connection between the program on the Arduino and the program on the computer was severed. Instead of running out of control, if the Arduino does not receive an update from the computer for more than one second, all of the pins are automatically switched off to stop the ROV from moving. If the program is reconnected, the Arduino will resume operating as normal.

Pressure Housing

Last year, we believed we could make do with a very simplistic waterproofing technique for our electrical systems on Tachyon Mk. II. We coated the sub-surface electrical boards in a liquid rubberized plastic, and this solution worked well—until the day of the regional competition, when the system failed catastrophically due to water intrusion.

The company realized that if we were to continue to develop electronics systems that require electrical systems to be kept below the water's surface, we would need to develop a pressure housing system. A pressure housing is a device used to keep electronics completely dry in a sealed volume of air. Initially, we designed a cylindrical pressure housing with a double o-ring seal in SolidWorks, and then machined it on a lathe out of 10 cm diameter UHMWPE (ultra-high molecular weight polyethylene) stock. The grooves to hold the o-rings had to be machined to within a quarter of a millimeter to attain the best possible seal, which was ultimately achieved after more than 20 hours of machining.

A ball valve was installed in the lid of the pressure housing to prevent air pressure from building up inside the housing when the lid was closed. Excess pressure would have made the housing difficult to close and could have caused the lid to pop off when the ROV surfaced. The seal of this housing was then vacuum tested, and it was found that a vacuum of 0.3 atmospheres could be held in the housing for several days with no discernible change in pressure—an ideal result.



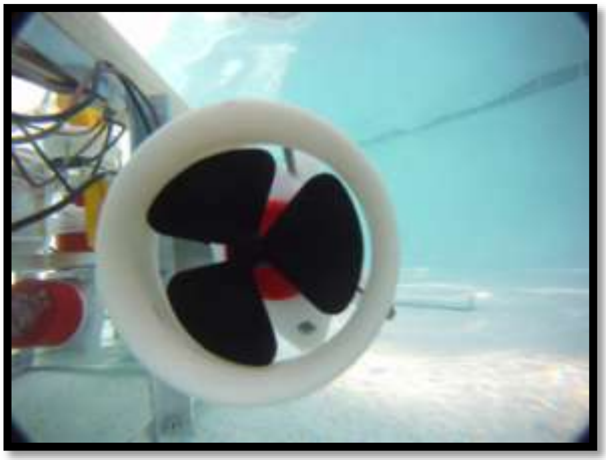
The final pressure housing is located in the middle of the robot and is visible in this picture.

Through-hull connectors inside the Otterbox©. These connectors lead to the thrusters.

We then drilled a series of holes through the pressure housing to accommodate the wires that had to run into the housing. However, we eventually discovered that the wires were leaking, an issue that we spent a great deal of time trying to correct. Eventually, we developed a sealed through-hull connector based on an epoxy-filled copper tube to which we could crimp our wires (see the Lessons Learned section for further discussion of these connectors). Facing a rapidly closing deadline for this system to be done, we decided to use an Otterbox© instead of starting over with our custom pressure housing, but to use the same through-hull connectors as previously. This Otterbox© also significantly improved the ease of access to the electronics systems, which aids in trouble shooting and fixing issues. As an additional precaution, we added a layer of desiccant to the bottom of the pressure housing to absorb any moisture that might seep into the housing before it can damage the electronics.

Propulsion system

To propel Tachyon Mk. III through the water, we initially planned on creating custom thrusters; however, we decided against this method after failing to find a motor that met our size and power specifications. Instead, we opted to use bilge pumps, which are already waterproofed and can be relatively easily modified to hold a propeller. We used modified 4,731 LPH Rule bilge pumps and added 3-bladed 60 mm Kort propellers. These thrusters were significantly more powerful than the bilge pumps with two bladed propellers we previously used, and also resulted in a lower current draw. The ROV is equipped with four interchangeable thrusters, two vertical ones and two for the horizontal plane.

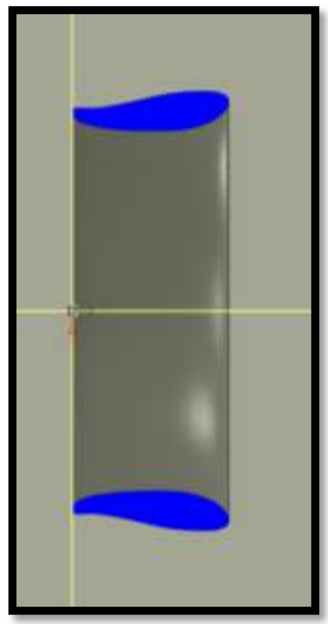


The nozzles mounted with the Kort props attached. In the final nozzle configuration, less than 1 mm of clearance exists between the ends of the propellers and the interior of the nozzle.

The maximum degree of pitch Tachyon III can achieve (the bow of the robot is at the surface).

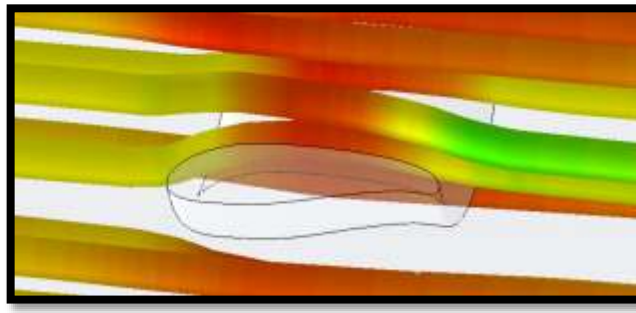
While researching ways to improve power output of the motors, we discovered a type of nozzle called a Rice Nozzle, which features a cross-section similar to that of an airplane's wing. This cross section accelerates water moving through the nozzle, increasing thrust. The Rice profile is optimized for use in both the forward and reverse directions, and is proven to outperform other forward/reverse nozzles including the more popular Kort nozzle profile [2]. We designed Rice nozzles to fit our propellers using Solidworks, and Nikolai Kochurov arranged for them to be 3D printed in ABS at the University of Alabama.

In addition to improving thrust output, these nozzles also make the robot safer by helping to keep foreign objects from entering the propellers. These thrusters are positioned to give us maximum pitch and turning abilities. Because the vertical motors have been spaced as far apart as possible, we are able to pitch at angles of up to 60° from horizontal orientation.



The nozzle profile in Solidworks©

We could clearly see a significant increase in the thrust output of the motors as soon as we put the nozzles on the ROV, but we wanted to quantify the improvement in performance of the thrusters. To do this, we built a simple thrust measurement system, based on a spring scale and a pivoting arm. The results of these tests are displayed on the following page in Table 2. The Rice nozzles resulted in an increase in thrust of approximately 40% in both the forward and reverse directions, and a decrease in current usage of more than 10% when compared to the motor with the same propeller but no nozzle. The improvements in performance are even more significant when compared to the less-efficient two-bladed propellers we used previously, as the Kort propellers with rice nozzles are able to produce nearly twice the thrust in both forward and reverse directions, while still drawing less power.



This picture shows a computational fluid dynamics analysis of our nozzle profile in Solidworks©. The tubes reflect the path of water around the nozzle, and the colors indicate the relative speed of the fluid at different points in its flow through the nozzle.

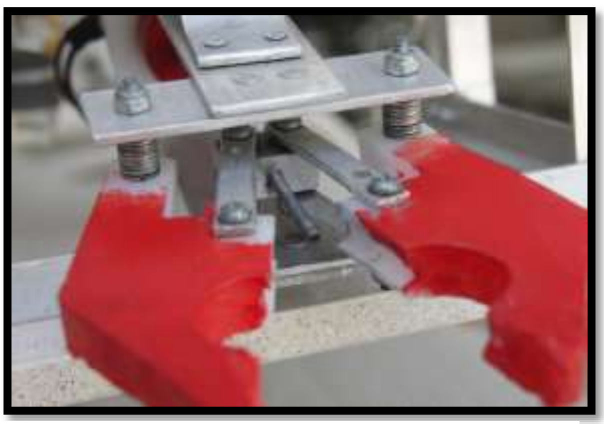
The old 2-bladed propeller (left) and the new, 3-bladed Kort propeller (right)

Table 2: Propeller Thrust Test Results				
	Forward Thrust (Newtons ± 0.1)	Current Forward (amps ± 0.1)	Reverse Thrust (Newtons ± 0.1)	Current Reverse (amps ± 0.1)
2 bladed prop	7.7	6.0	2.7	6.2
Kort prop	9.8	5.7	3.1	5.3
Kort prop w/ nozzle	13.8	5.1	4.6	4.8

Gripper

The gripper is a crucial part of our plan to perform a majority of the tasks on the shipwreck. Over the past two years, we have experimented with a variety of gripper designs, which we have used to make this year's design as sturdy and as simple as possible.

The company decided against using fluid power systems for several reasons. It is more difficult to control the speed of a pneumatic actuator than it is to control the speed of an electromechanical one; additionally, the mass of the actuators and additional bulk of the air lines in the tether would have significantly slowed the ROV down. Also, all cost-effective pneumatic actuators were too massive for the ROV we intended to build. Therefore, we decided to use an electromechanical system, based on the same bilge pump motors as our thrusters, which could also make use of the electrical power already being supplied to the ROV. To convert the rotational energy from the motor into linear movement, we used a 10-32 threaded rod, which is passed through a block of aluminum tapped to match the thread on the rod. As this aluminum block moves, it pushes against four rigid aluminum linkages, which in turn push the jaws of the gripper apart. The jaws of the gripper are made of 1 cm thick Delrin. The gripper was painted red to improve contrast between the gripper and the bottom of the pool or the mission props, which makes it easier for the pilot to see the gripper on the monitors.



The linkage used to convert rotational to linear movement can be seen in the middle of this picture, between the two jaws

A major issue encountered with the gripper was that the set screws in the aluminum coupler responsible for transferring power from the motor drive shaft to the threaded rod would repeatedly strip the threading out of their holes, preventing us from tightening the coupler down far enough to actually grip the motor shaft properly. After destroying two aluminum couplers in this manner, we decided to create a new, stronger coupler. We machined a new coupler out of stainless steel, a much harder and stronger metal than aluminum we used previously, to produce a superior and more effective coupler.

The new custom machined steel coupler (back) and the old commercial aluminum one (foreground)

Historically, we have had major problems with the gripper "jamming" as it reached the limit of its travel at either end of the threaded rod. The motor would continue to exert torque on an object that could no longer move, which resulted in the steel screw jamming in the threaded aluminum block. This often occurred with such force that the gripper would become completely seized, necessitating a trip to the surface to be fixed. This year, we solved the jamming problem by implementing a PWM system for the gripper. The gripper now runs at 50%

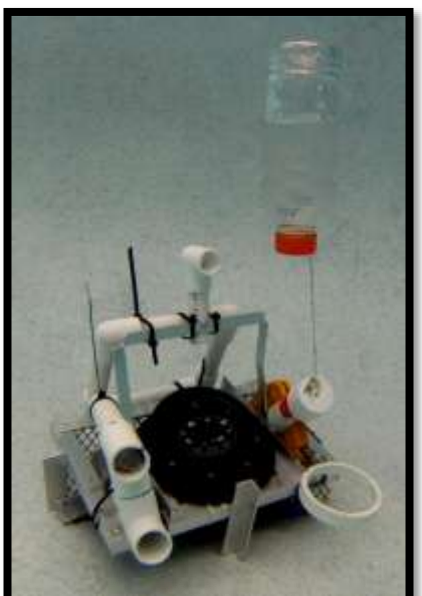
power; if it jams, the power can be increased through the program running on the computer to allow the gripper to have enough power to un-jam itself instead of returning to the surface.

Tools

In addition to the tools and devices integrated into the ROV, we also produced several stand-alone tools that the ROV uses with its gripper. These are kept in an submersible basket when not in use. The use of separate tools simplifies the ROV's design and allows for the use of specialized tools.

Compass: A fluid-filled marine compass attached to the underwater tool basket is used to determine the orientation of the shipwreck. We originally planned to use a digital compass mounted on the ROV itself, but initial tests showed that interference from the permanent magnets in the motors on the ROV would prevent us from achieving an accurate orientation readings. When the compass is outside the ROV, such interference is no longer an issue, as the ROV can move away from the compass to achieve an accurate, interference-free reading. The basket with the compass is maneuvered into position by the ROV; once it is aligned with the shipwreck, the pilot reads the compass using the forward facing camera.

Tape Measure: The tape measure, consisting of an off-the-shelf nylon coated steel wind-up tape measure with a few modifications, is used to measure the length of the shipwreck. A PVC handle was attached to the top of the tape measure casing so it can be easily gripped by the ROV. An air-filled water bottle is tethered to the tape measure to make the tape measure neutrally buoyant and to keep the handle upright. A PVC ring on the end of the tape is used to attach it to the vertical post on the bow of the shipwreck.



From left to right: the ultrasonic thickness gauge and neutron backscatter device, the compass and the tape measure in the ROV's tool basket.

Ultrasonic Thickness Gauge and Neutron Backscatter Device: These two simulated sensors are integrated into one device so that they can be more easily carried by the ROV in order to cut down on mission time. The device consists of a vertical PVC handle that fits into the gripper, from which the two sensors extend horizontally. The ultrasonic thickness gauge contains foam to make the top half of the combined sensor unit positively buoyant, ensuring that the device remains upright when it is resting on the bottom.

Debris Sensor: Our debris sensor is designed to be as simple as possible, and consists of a small but powerful neodymium magnet mounted on the end of a 5 cm steel spring. If the magnet sticks to a debris pile, the spring will bend, indicating that the debris is ferrous. This deflection is visible on the rear facing camera.

Oil Sampler: Like the debris sensor, the oil sampler is integrated into the ROV. It is composed of a probe, plastic tubing, a submersible water pump, and a collection balloon. The probe consists of a UHMWPE tube, with a 3 mm hole running almost the entire length, except for the last 1.5 cm of the probe. The tip of the probe is sealed and has a tapered, widened portion designed to penetrate the petroleum jelly on the fuel tank while preventing the inlet holes from becoming obstructed. Four holes are drilled from the sides of the probe into the center of the tube, about two centimeters from the tip of the probe. These inlet holes intersect with the center tube and serve as inlets to allow the oil sample to enter the probe. The back end of the probe has a plastic disk five centimeters in diameter that covers the fuel tank opening while the probe is inserted preventing outside water from entering the tank or probe and diluting the sample. The opening at the back end of the probe is connected through plastic tubing to a submersible water pump on the ROV. When powered, this pump pulls the sample through the probe and then transfers it into the balloon, which serves as a collection reservoir. The system must be primed and flooded with water before use because the pump is impeller-driven and the presence of air in the system prevents it from functioning. To facilitate priming the pump, a removable syringe is attached to the plastic tubing inline between the probe and the pump's inlet. This syringe is used to fill the pump and tubing with water so the pump functions properly. The probe is mounted on the stern of the ROV next to the ferrous debris sensor.

Tachyon Mk. III's sampling probe

Cameras: Tachyon Mk. III has three commercial waterproof analog video cameras. Each camera has its own cable within the tether that combines power and signal lines. These cameras were chosen for their simplicity, relatively high quality, and price. The navigation camera is mounted to the right of the pressure housing facing forward. It is also used for scanning the sonar targets and reading the compass. The second camera is attached to the top of the ROV on the port side near the bow. It faces at a downward angle, providing a view of the gripper and its surroundings. This camera is used primarily for positioning the gripper and seeing objects that are below or close to the front of the vehicle. The third camera is mounted below the pressure housing, facing out the stern of the ROV. It has a view of the back of the ROV, as well as the oil sampler and the debris sensor. This camera aids the pilot when the ROV maneuvers in reverse, and is used to position the sampling probe and the ferrous debris sensor. Mounting brackets were fabricated from angled aluminum to hold the cameras in the positions desired.

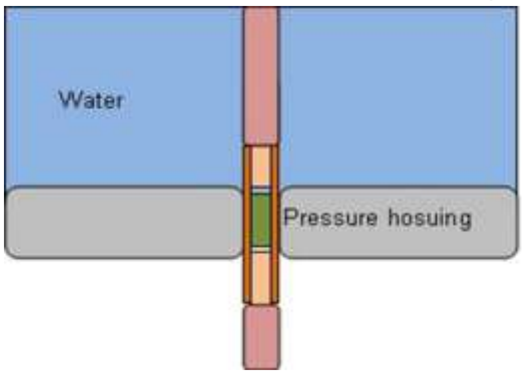
Challenges Faced and Lessons Learned

One of the most difficult challenges we faced was developing a functional pressure housing for our electrical systems. After putting wires through the original pressure housing, we took it along on a scuba diving trip to see if the housing could keep the water out at depths up to 15 meters. After surfacing, it was determined that water had gotten into the housing. However, the source of the water was unclear, and remained unclear despite several further rounds of testing using a vacuum pump. After filling the entire housing with colored water and

The original pressure housing

pressurizing it to 2 atmospheres (203 kPa), it was discovered that water was flowing through the wires in-between the metallic core and sheathing, and using the wires as a conduit into the pressure housing. To keep to our principle of cost effectiveness, we rejected a commercial solution to seal the housing, such as the through-hull water proof connectors offered by many companies. Instead, we decided to design and build our own.

We discovered that the copper wire we were using would fit perfectly into a segment of 1/8" copper tubing. From this, we developed the idea of having a 2.5 cm segment of copper tubing, with the copper wires sticking 0.75 cm into the tube. Epoxy was used to fill the remaining 1 cm in the middle of the tube, rendering the connection between the two wires watertight. The copper tube penetrated through the wall of the pressure housing, and was sealed around the hole with epoxy. Since copper is conductive, the wires could be crimped at either end, forming a continuous electrical path without water seeping through.



An illustration of the through hull connectors devised by the company. The green is the epoxy plug, the light brown is the wire, the dark brown is the copper tube, and the light red is the insulation on the wire.

However, by the time we had completed this design, we were running out of time to finish the pressure housing. We had a fixed deadline: if the housing was not completely operational by the end of January, we would purchase a commercially waterproofed Otterbox© and modify it to meet our needs instead. When the valve used to equalize pressure in the housing began to fail, we decided to move on to our secondary plan, so that we could still make our deadline.

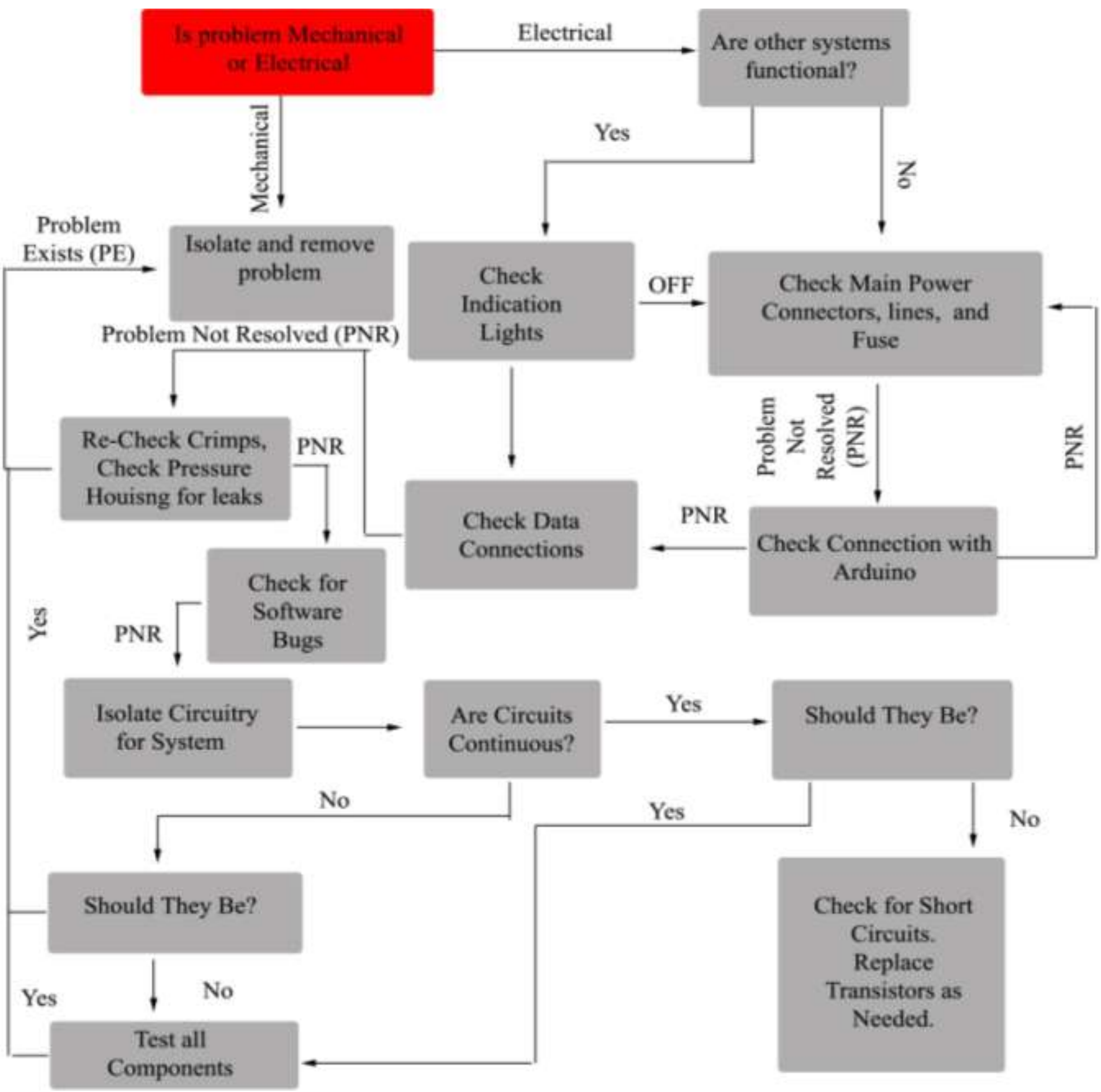
We learned two things from this experience. We discovered that, in many cases, components thought to be infalible (such as wires) could be the cause of failure of a system. Second, we also learned knowing when to move on with a project can be just as valuable as perseverance and dedication to an original design plan. The original pressure housing was well designed; we invested over 100 hours in constructing and testing it. Unfortunately, component failures and unforeseen difficulties made this housing a liability to the team, slowing down the project and preventing us from getting in the water and practicing the mission tasks. Therefore, we made the decision to move on to our alternate plan.

Additionally, we faced a significant non-technical hurdle early in the season. For several months, the team struggled with organizing meetings. We eventually realized that every member of the team must share the same level of commitment to the project; however, this commitment was not universal among members. Ultimately, the problem was resolved through a series of discussions about what was required for the team to function, after which two of last year's team members did not to return. Additionally, we moved our build location to ensure that we would be able to meet whenever necessary to complete the ROV on schedule, and the project was split into components, each of which was assigned to a different person.

We also moved from scheduling meetings on a week-to-week basis to a long-term schedule, which allowed us to more efficiently plan meetings and produce a development schedule for the project. We learned that the use of a long term schedule is invaluable in helping everyone keep focus and we also found that ensuring each person had a substantial role in building their own components for the ROV allows team members to maintain a high level of commitment to the project. We discovered that people become more committed to the project and are more interested and involved when they lead development of a specific part or system. To make use of this, everyone was assigned a specific system to lead production of, a method which worked well in ensuring that everyone contributed to the project, while maintaining team coherence.

Troubleshooting Techniques

A major challenge we faced while building the ROV was troubleshooting. Even after hours of reliable performance, our ROV sometimes exhibited anomalous behavior. It became necessary to formulate a method of troubleshooting. In order to ensure that our company could arrive at and solve any problems on the robot quickly, we developed a system to isolate and diagnose problems. This



flowchart is used to diagnose and fix mechanical and electrical problems on our ROV, and has been successful for identifying a variety of problems over the development season.

Future Improvements

For the 2012 competition, Tachyon Robotics engineered a robust and powerful robot. Although it performs well, this design could be improved in many different ways. In spite of this year's massive improvement over previous control systems, there are still major gains which could be made.

The control system used on Tachyon Mk. III has the two vertical motors sharing a modified H-bridge. Each motor can be throttled forward or reverse independently, but their speed cannot be throttled independently. If the pilot wants to pitch the robot, one motor turns forward, and the other turns in reverse. If the pilot wants to move up or down, the motors turn in the same direction in either forward or reverse. Because both verical motors are throttled to the same speed, the pilot is unable to simultaneously change the ROV's elevation, and pitch the bot to keep something in view. This problem might be solved by redesigning the circuitry with a separate PWM controlled H-Bridge for each vertical motor.

Another issue that emerged during practice is that the robot lacks a method to adjust its position lateraly. If the ROV draws near to a target location and drifts to the left or the right as it approaches, the pilot will have difficulty returning to the target without changing the robot's orientation to it. Simply turning the robot to the left or right will correct the robot so that the front is pointing the right direction, but the orientation will be different. There are several tasks in the 2012 mission tasks that require specific orientation, such as patching the hole drilled in the ship hull. The magnetic patch will stay on only when it is pressed flat against the hole. Additionally, it is occasionally troublesome for the ROV to maneuver around the shipwreck when it is parallel to the hull. Simply turning the robot away when it is close to the shipwreck might ram part of the ROV into the hull. The best solution for the pilot in these situations with the current implementation is to back off and reapproach the target location, which is time consuming and the robot might drift off once more in the process. The addition of strafing motors would benefit the pilot because he would not have to leave the target region and approach it again, but instead realign the ROV by maneuvering laterally.

Safety

Safety is a major concern for Tachyon Robotics. We enacted several safety procedures while building the robot. Engineers wore eye protection whenever they used machine tools. Team members wore gloves when they used rotary cutting tools like the bench grinder or Dremel and when handling acidic etchants.

Safety features are also integrated into the final ROV. A 25 amp fuse is connected in series with all circuitry on the ROV. If the ROV draws excessive current, the fuse will blow, protecting the circuits from the short and anybody who could potentially be injured by such a catastrophic event. The current draw is continually monitored, and is displayed by an ammeter mounted in the Pelican Case used to house the above water electronics.

We also have a switch on the control board next to the pilot. Opening it cuts off power to the entire ROV. Should an electrical problem occur which causes the pilot to lose control of the ROV or a propeller become entangled, all power to the motors can be cut off by flipping this switch. Additionally, whenever a team member approaches the

ROV to inspect it or work on it, this switch is turned off, to avoid the risk of accidental activation of the motors.

The 'Start' button on the Xbox 360 controller is dedicated to locking input. When the pilot presses this button, no input from the controller is accepted. Pressing it again enables the controller again and it operates normally. The pilot can use this feature when he wants to put down the controller, preventing accidental input which could cause the motors to run.

Several modifications have been made to the ROV to improve safety. The ROV's corners are filed down so that handlers will not cut themselves on the frame as they move it around. The motors are surrounded by rice nozzles, which stop foreign objects from entering the blades and causing damage to the robot and the object. Labels have been added to the ROV to advise users of potentially hazardous components or sections of Tachyon Mk. III.

Reflections

I have thouroughly enjoyed working on the ROV over the past three years. Having had the experience of conceiving of a system, and to then develop it in a real-life engineering situation has been exceptionally enriching. Through my experience as a mechanical engineer on the project, I have learned a variety of skills that I would otherwise have lacked. These skill include the ability to design and model objects in CAD software, and physical machining techniques, such as the proper use of lathes and drill presses. Although it ultimately failed, the experience of designing and then building the original pressure housing out of UHMWPE stock─from the first sketches of the housing to finding stock of an appropriate plastic to refining the design, machining and testing the housing─has been one of the most fulfilling parts of the project for me. I have decided to major in mechanical engineering largely based on my experiences with the MATE ROV competition.
─Kieran Wilson

Kieran Wilson lathing the oil sampling probe.

My experience as Electrical Engineer in the MATE ROV competition has been one of the most enriching experiences of my life. Perhaps one of the greatest memories I have of the project is the day when we were finally able to prototype circuitry to interface with our Arduino microcontroller. I had spent months trying to gain a better understanding of circuitry design and transistor operation and along the way produced a few failed prototypes, and therefore it was an amazing moment when I was able to see the speed and direction of our motors controlled by our custom designed circuitry. This accomplishment is one of my greatest memories from the project, but more influential were the hours spent in attaining it. Through the MATE ROV competition, I found out that I greatly enjoy designing and testing circuitry, and therefore decided to study

electrical engineering at the University of Alabama this fall.
─Michael Ikegami

Building software and piloting the ROV for this competition has taught me a lot about the construction of integrated systems. I have learned about everything from aspects of the Object Oriented Paradigm, to low level logic in the Arduino Microcontroller. Creating a functional system required dozens of hours of trial and error. But what was more important than any particular piece of information that I have picked up on the way is the practical experience I have gained from this competition which I will be able to apply in the future as I pursue a career in computer engineering. It has certainly been an exceptionally rewarding experience for me and for the rest of the team.
─Sam Knight

Participating in the MATE ROV competition has been an incredible experience. Working on such a complex project has helped me learn new skills and greatly improve my abilities while providing valuable practical experience that will benefit me in my future work and studies. Among other things, I have learned metal and plastic fabrication techniques and how to work with CAD software. Seeing the project as it has developed over time from a few scattered ideas into a fully-functioning ROV has been a very gratifying experience. My experiences as a competitor in the MATE competition have helped me to decide to follow a career in engineering after high school.
─Evan Terry

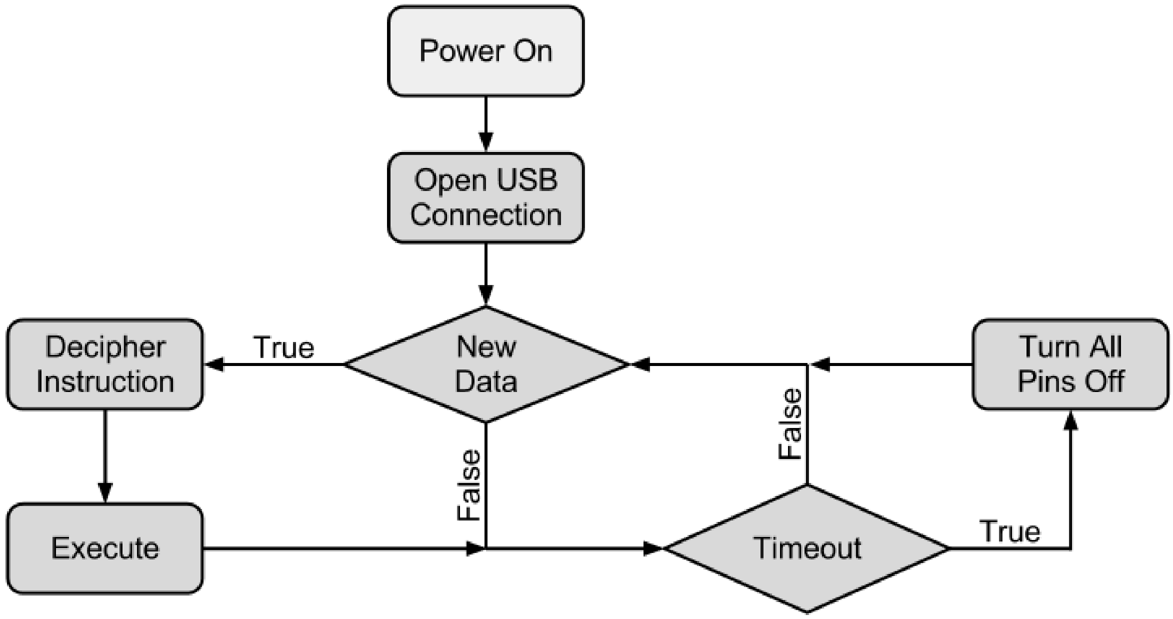
Acknowledgements

Tachyon Robotics would like to thank the following:
Mr. Joe Wise, for his continuous support as our mentor over the past three years. He has always been ready and willing to assist us whenever we need it, and also has purchased our mission props to allow us to practice every year.
Lenco Marine for the generous donation of three waterproof linear actuators to the team, which were used in the development of various gripper designs;
The Geneva School, Rev. Robert Ingram and the Reynolds Family for their financial support;
Dr. Stuart Lilie, for providing us with access to his incredible machine shop and instruction in how to safely use it;
The Julin Family for generously loaning us a variety of tools, from a drill press to a bench grinder;
Trinity Prep Aquatics for proving us with opportunities to practice in a pool at competition depth;
Mr. Nikolai Kochurov, Dr. Shane Sharpe and the University of Alabama Computer Based Honors Program for printing our nozzles;
And **Alro Metals** for discounts on aluminum and Delrin stock.
A special thanks to the **MATE Center**, for providing us the opportunity to compete in this competition.
We would also like to thank all those whose garages we have invaded over the past years, and all of our families for supporting us and helping us through donations of food, time, patience, advice and money. Thank you!

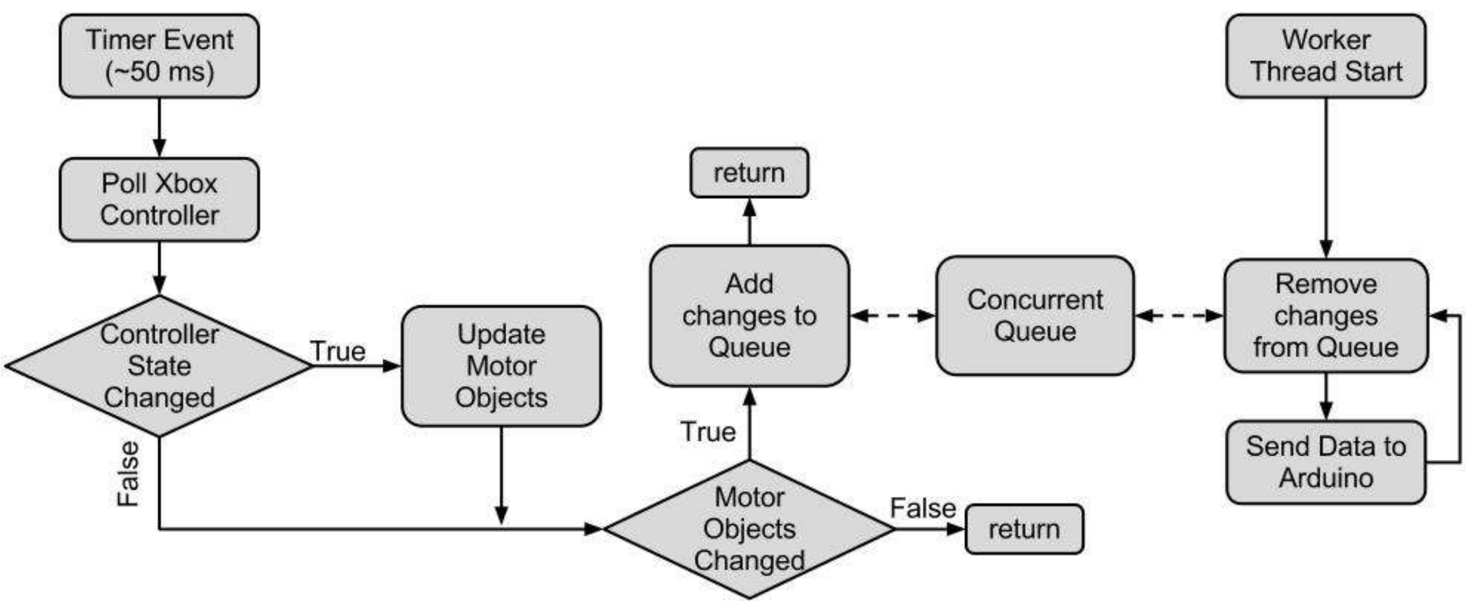
Sources:
[1]: "Corecell A-Foam datasheet." *Gurit Corecell*. Web. 2 May 2012. <http://fr.gurit.com/Files/Documents/English Datasheets/Corecell A Foam_v7 SP.pdf>.
[2]: "How Marine Nozzles Work." *Propeller Pages*. Web. 2 May 2012. <http://www.propellerpages.com/?c=nozzles&f=How_Nozzles_Work>.

Appendices:

Software Flowcharts:



Flow chart for program running on laptop



Flowchart for program running on the Arduino

Cost Spreadsheet:

Part	Total cost	Value of donation
Aluminum for frame	$80	
Lammensco SC420 Cameras (3)	$225	
Corecell A400 High Density Foam	$40	
12v Submersible Pump	$10	
PVC pipes and fittings for mission props		$120
1100 GPH bilge pumps (8)	$304	
Rice nozzles (4)		$116
Lathe and Machine Shop Access		$500
UHMW PE for probe		$8
3/8" Tubing	$3	
Threaded Rod	$10	
Arduino Mega (2)	$140	
Copper Clad and Etchant	$70	
Solder and Flux	$10	
Discrete Electronics (Transistors, Relays, Diodes)	$174	
Otter Box (2)	$60	
Cat5e (1000 ft)	$60	
Lamp Cord	$80	
Wire Sheathing for Tether	$30	
Delrin		$40
Misc Electronics	$55	
Epoxy	$50	
Rivets, Screws, Locknuts, Zip Ties Set Screws	$30	
60 mm Kort Propellers (6)	$50	
Motor Couplers (5)	$30	
Pipe insulation Foam	$10	
Marine Compass		$40
Solidworks		$125
Donation from Robert Ingram		$100
Donation from the Reynolds Family		$200
Winnings from Florida Regional Competition (Donated by Videoray and Crockett's Challenge Fund):		$200
Lenco Marine Waterproof actuators (3)		$750
Totals:	$1,521	$2,199
Grand Total:	$2,470	

Note: The grand total reflects the total value of the parts and services used to create Tachyon Mk. III.