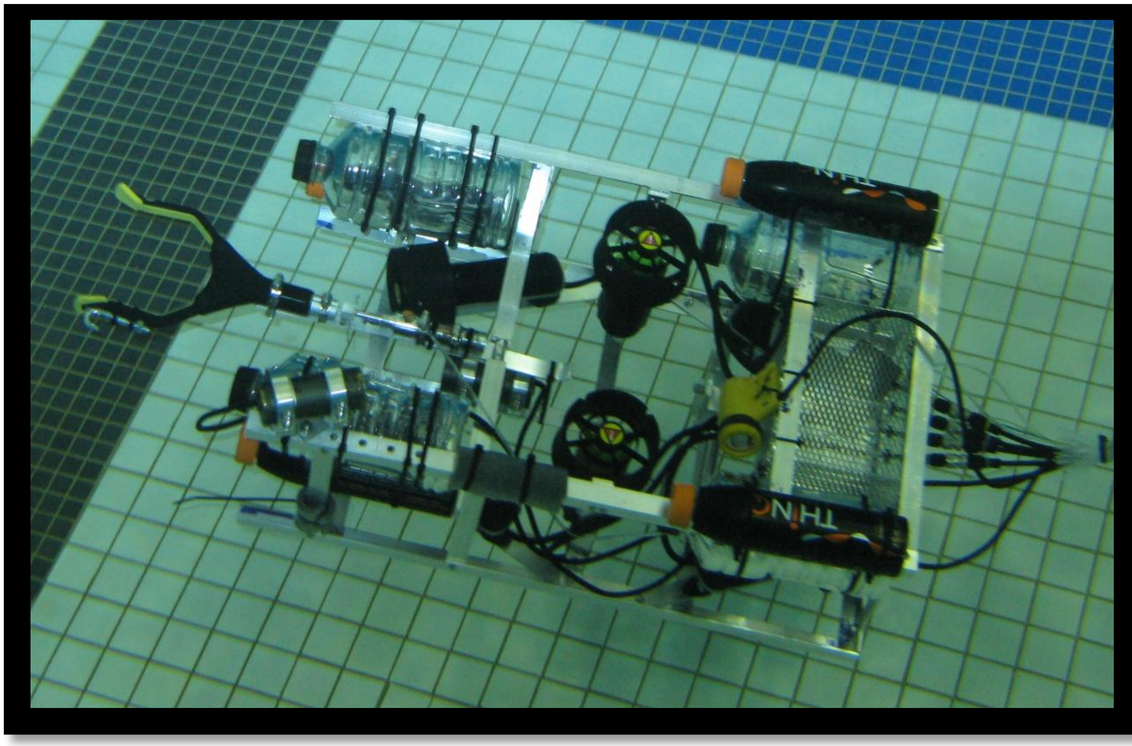
Purdue University IEEE

West Lafayette, Indiana, USA

Explorer Class



<u>ROV *Competence*</u>

Technical Report

2010 MATE International ROV Competition

ROVs in Treacherous Terrain: Science Erupts on Loihi, Hawaii's Undersea Volcano

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Abstract

ROV *Competence*, the second vehicle created by the Purdue University IEEE ROV team, has been designed to accomplish and exceed the 2010 MATE International ROV Competition mission requirements. The vehicle is designed with a focus on reliability, handling, and dexterity. This focus stems from the challenges presented in this mission and in the history of volcano study. All of these goals were to be accomplished within a final vehicle cost of approximately $6,000 (not including the cost of research, testing, and transportation).

The vehicle is designed to deploy testing equipment near seismic activity, collect a sample of a new species of crustacean, test water temperature at multiple vent sites, and collect a specific sample size of bacterial mat. ROV *Competence* accomplishes all expected tasks in a single dive while remaining only 60cm long, 35cm wide, and 22cm tall.

This report covers the specifications and design process of the Purdue University IEEE ROV, ROV *Competence*.

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1. History: The Loihi Seamount

This year's MATE competition was inspired by the Loihi seamount and the expeditions that have explored it. As students and competitors, it is important to study the seamount itself and the processes behind it as well as the purpose of the expeditions to the seamount. This information greatly affects the design process and helps to inspire new ideas in the minds of the team members. The previous expeditions serve as a starting point, but it is the goal of the competition and its competitors to find new and innovative ways in which to conquer the challenges the seamount presents.

In July of 1996, a series of seismic events began which formed the Loihi seamount. The entire set of events occurred between mid-July and early August consisting of four thousand small earthquakes. These earthquakes were caused by hot magma rising to the surface underneath the sea floor. Research indicates that some of the magma may come from the main volcano, Muana Loa, on the island of Hawaii. The seamount is one of the youngest in the Hawaiian islands and is still active today.

Figure 1.1 - HUGO at the Loihi seamount. (courtesy of Hawaii Center of Volcanology)

There were many research explorations launched to explore the Loihi seamount. The earliest explorations were conducted by Pisces V and were concerned mainly with collecting rock samples to be analyzed by several different methods in order to determine the chemical makeup of the seamount. The latest explorations have been performed by HUGO, which monitors the seamount for recent activity. HUGO also records sounds from around the seamount, increasing the types of data scientists can analyze.

Figure 1.2 - Pisces V being deployed at a site. (courtesy of NOAA)

This year's mission incorporates HUGO and encompasses its tasks as well as some of the tasks the Pisces V manned submersible performed. One of this year's mission tasks is to determine locations of seismic activity and move HUGO. This essentially re-deploys HUGO to a more active spot in order to obtain better data as the young seamount develops. Collecting various samples of crustaceans and agar are reminiscent of the Pisces V explorations, giving us a better idea of the life and environment around the seamount. It is the goal of this competition and ROV Competence to perform these tasks and more.

See Section 8: References/Works Cited for researched sources

2. Mission Summary

Competition Tasks and how ROV Competence does them

Task 1: Resurrect Hugo

The mission begins by using the ROVs hydrophone to identify a potential 'rumble' site. The vehicle is piloted to each site with the laptop speakers indicating whether or not that site is making noise. The pilot can record the frequency displayed on the laptop monitor if necessary. ROV *Competence* then uses its manipulator to grab and pull out the two pins holding the HRH (high-rate hydrophone) to the elevator used to lower it to the ocean floor. To make this task easier, the pilot can rotate the manipulator down to grab the pins while hovering above the elevator. The HRH is then grasped by the manipulator and brought to the correct 'rumble' site previously identified. The HRH is activated by plugging it into the junction box of HUGO. ROV *Competence* grabs the cap to the HUGO port using the manipulator grippers and drops it on the pool floor. It then grabs the plug, left at the elevator, and plugs it into HUGO.

Task 2: Collect Samples of a New Species of Crustacean

The ROV's small size and thruster layout makes maneuvering inside the cave where the crustaceans are located an easy task. The crustaceans sitting on the back wall of the cave are retrieved using ROV *Competence's* rotating manipulator. Then the manipulator rotates back to store each crustacean in the basket in the rear of the vehicle. The mesh design of the basket prevents the crustaceans from falling out while maneuvering. The rear-facing camera assures that the crustaceans are still in the basket in addition to aiding the ROV in backing out of the cave.

Task 3: Sample a New Vent Site

ROV *Competence* has a thermometer mounted on its rotating manipulator to sample the three required vent sites, regardless of the angle they are presented. The temperature is displayed on the laptop monitor. The pilot then uses the manipulator grippers to grab and hold on to a vent spire sample. This is done at the end of the mission so that the spire can remain in the grippers and be brought to the surface without inhibiting the ability of the ROV to complete the mission in one dive.

Task 4: Sample a Bacterial Mat

The agar (simulating a bacterial mat) collection system is deployed from the center of the vehicle by a pneumatic piston that rotates a hinge. This collection system is a cylinder with a one-way valve which allows water inside the cylinder to vent, but creates a vacuum seal once the agar is retrieved to keep it inside. Once deployed, the pilot maneuvers over the agar sample and lowers the vehicle until the cylinder has cut to the bottom of the sample.

3. Design Rationale

3.1 Frame

The frame of ROV *Competence* is shaped around the systems designed for the mission. The one-manipulator design gives the ROV its initial shape of manipulator in the front and tether in the back (to stay out of the manipulator's way). The rotation of the manipulator required the design to be very open at the top with added support on the bottom to compensate. The frame's bottom took shape first to accommodate its four relatively large Seabotix BTD-150 thrusters.

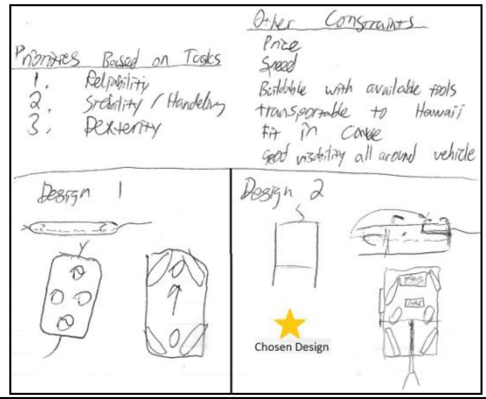

Figure 3.1 - Initial drawings of ROV *Competence* made on a overhead projector

This layout was first drawn out on paper in a classroom on an overhead projector with the whole team contributing ideas. That rough draft was sketched in to Google SketchUp, a very basic CAD program. The program was a great way for the team to "pass" the design around and make many quick, small changes before the final design emerged. Once the design accomplished all the goals originally set by the team, the ROV was sketched in Solidworks with more specific dimensions than the Google SketchUp drawing.

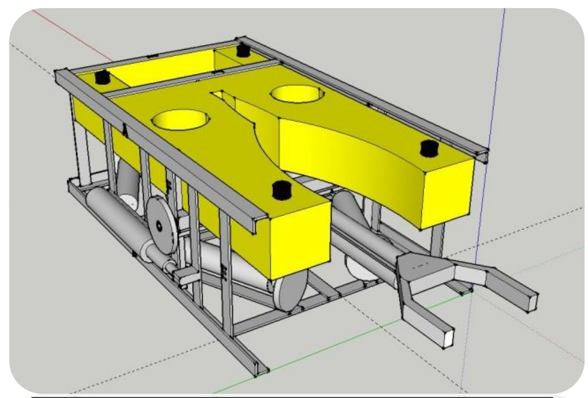

Figure 3.2 - "Rough draft" of ROV *Competence* in Google SketchUp

Once drawn in Solidworks, the team used a Haas CNC Mill available in the Purdue Artisan and Fabrication Lab to drill holes in flat bars and angles of aluminum. The 0.3cm thick aluminum was chosen due to its corrosion resistance, strength, and low density. All frame parts are held together with size 8 stainless steel bolts and nuts.

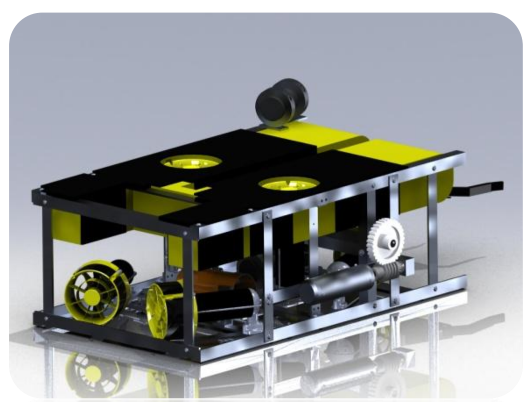

Figure 3.3 - Full render of completed ROV *Competence* in Solidworks

3.1 Frame (continued)

Figure 3.4 - ROV *Competence's* frame being cut in a Haas CNC Mill

Figure 3.5 - The first time the main frame of the ROV was put together in the workshop (bolts not tightened)

3.2 Manipulator and Basket

ROV *Competence's* manipulator is designed with the mission in mind. To keep the ROV light, compact, and simple, the team decided on only one main manipulator for all tasks. This means that the grippers on the manipulator must be precise enough to grip crustaceans for collection while opening wide enough to hold a vent spire sample. The team experienced great success during the 2009 competition utilizing a commercially made 'reacher' called the PikStik grabber. The PikStik is modified with a 1.9cm diameter, double-acting pneumatic piston which is controlled by a valve from the surface. This piston runs at 275 kilo-pascals. The necessary closing force, determined by hanging weights from the cord that operates the gripper, had to be a balance between strength for the vent spire and HRH deployment and the ability to handle the delicate crustacean samples.

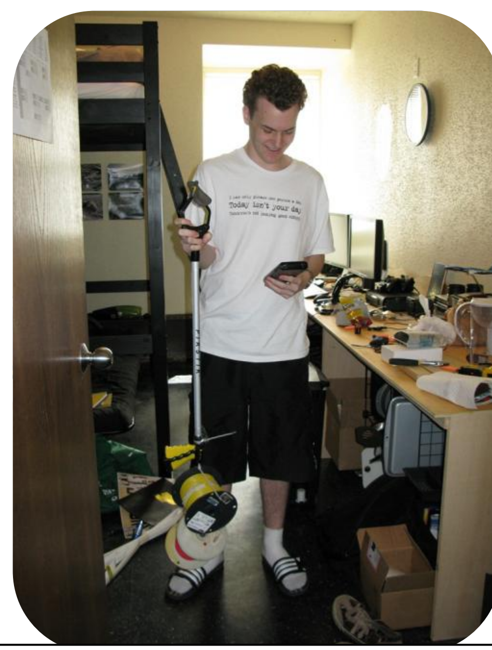

Figure 3.6 - Testing different closing forces to determine required pneumatic cylinder size

3.2 Manipulator and Basket (Continued)

ROV *Competence* is designed to collect three crustaceans and a spire sample in a single dive. To meet this self-imposed challenge, the team designed an on-board storage system to store the crustaceans while the other tasks are accomplished. To remain simple and reliable, a fixed basket is placed on the vehicle for this purpose. The basket is made out of expanded aluminum mesh. This material was chosen because it is light, durable, and hydrodynamic. The width between each strand of mesh is only 1.5mm, much smaller than any of the crustaceans expected. The dimensions of the basket itself are 8cm tall by 10cm long by 15cm wide. Because the basket is fixed, the manipulator must move to the basket. The basket sits in the rear of the vehicle and the manipulator rotates vertically in a 150 degree arc to drop crustaceans into it. This rotation is powered by a worm gear assembly (see Thrusters section for details), chosen for its high torque and reduced back-drive, enabling the manipulator to hold its position. The worm gear is powered by an electric motor in a custom enclosure.

3.3 Agar Collection and Transportation System

The agar collection system is based on the knowledge that the supplied agar is fixed at a height of 6.75cm. Given the range of volume of agar that needs to be collected (101mL to 175mL) the target for a perfect agar sample is 138mL. Using a 2.55cm radius cylinder dropped to the bottom of the sample container, a near perfect sample can be obtained almost every time. The cylinder that best matches these criteria is a large pill bottle from Walgreens Pharmacy, which they generously donated. Placed near the center of the vertical thrusters, the ROV uses these thrusters to descend and cut in to the agar.

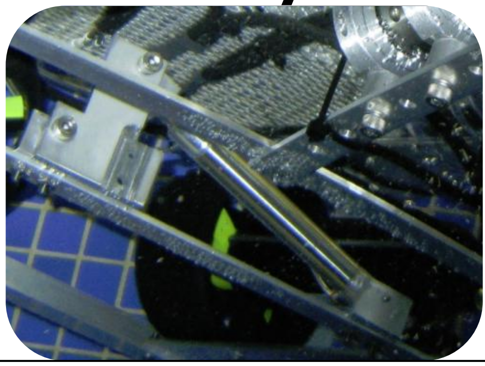

Figure 3.7 - Deployment system of agar collection tube (without agar cylinder attached) currently in the deployed position

To maintain the one-dive design, the team knew the agar collection system could not remain locked in position below the vehicle. A pneumatic cylinder attached to a custom hinge system deploys and collects the agar in under two seconds. A one-way valve is put in place on top of the cylinder to create a suction that keeps the agar in place.

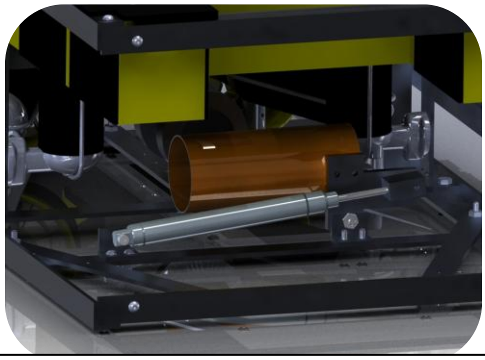

Figure 3.8 - Agar deployment system in stored position (Note: Parts are hidden in this image)

3.4 Thrusters

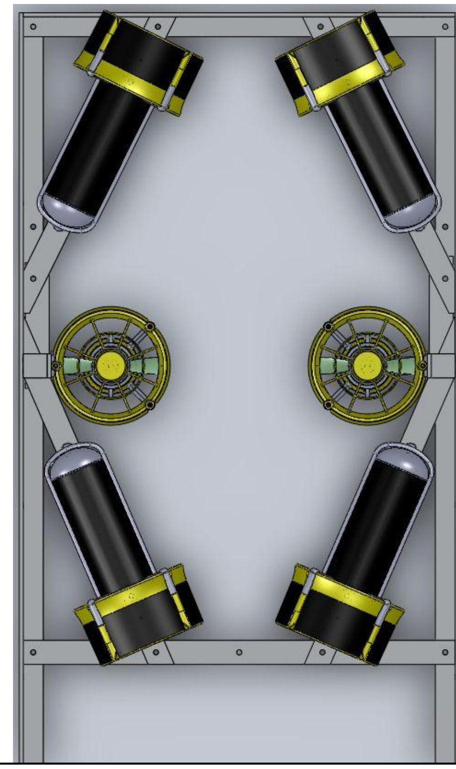

Figure 3.9 - Layout of thrusters in ROV *Competence* as seen from above

ROV *Competence* uses six Seabotix BTD-150 24Vdc thrusters. These thrusters were chosen because they were the best available mix of performance, weight, size, and affordability. They each produce 28.4N of thrust with a length of just 17cm. Four thrusters are placed at a 25 degree angle offset (see figure 3.9) for surge, yaw, and sway. Two thrusters are placed next to each other near the center of the vehicle for a balanced ascent. The positioning of the two thrusters favor roll over pitch because pitch control is not necessary due to the design of the manipulator system.

The original design used six brushed DC motors in custom enclosures. These units, inspired by the thrusters used on the 2009 Long Beach Community College ROV, were designed to provide optimal performance for this year's challenges. The design focused around a surplus DC motor press fit in a thin wall aluminum tube. The motor is run at 48V, providing 120W with only 2.5A. The low amp draw was favored due to the requirement that four motors must activate whenever the ROV is surging, swaying, or yawing. The enclosures were waterproofed with duel o-ring seals between the aluminum tube and aluminum end caps. The front end cap contains a spring-reinforced PTFE shaft seal. Manufacturing proved to be more challenging than originally expected. Despite this, one prototype was completed, and due to its high power output has instead been chosen to power the rotation of the manipulator at reduced voltage.

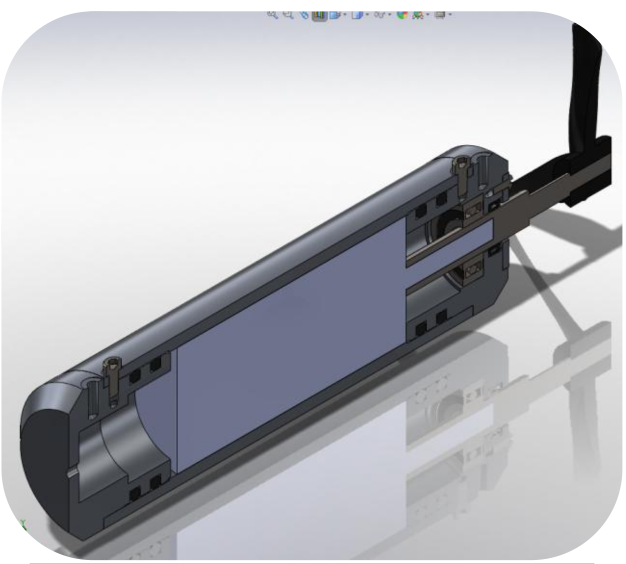

Figure 3.10 - Custom thruster enclosure originally intended to be used for all thrusters, now being used for manipulator rotation

3.5 Cameras

Two types of cameras are on-board ROV *Competence*. Two LightsCameraAction LCA-7700 cameras are used; one for forward vision and one for backward vision. The front camera is mounted near the center of the vehicle looking straight towards the manipulator. The rear facing camera is on top of the frame near the front. This camera allows us to see the status of the ROV and tether as well as exit the cave safely. These cameras were chosen due to the incredible image quality the team experienced when used on last year's vehicle, ROV *Osprey*.

Figure 3.11 - Image quality of the LCA-7700 camera on-board Purdue's 2009 vehicle, ROV *Osprey*

A third camera looks straight down at the agar collection system to aid in collecting agar as well as show how far off the ground the ROV is. This camera is a Vissior SC-420. This was chosen because it is the lightest and most affordable color camera available.

Figure 3.12 - Rear facing camera mounted on top of the ROV near the front (Note: Buoyancy in photo was temporary)

3.6 Hydrophone

The hydrophone used is a simple, passive hydrophone coated in black non-toxic rubber made by Cold Gold Audio in Vancouver. This hydrophone is run through the tether in an analog feed. At the surface it is amplified by a 12Vdc amplifier before being plugged in to the laptop. The laptop identifies and displays the frequency and also plays the audio out of the laptop's speakers.

Figure 3.13 - Passive hydrophone (courtesy of Cold Gold Audio)

3.7 Thermometer

The thermometer is an LM35DZ temperature sensor. The LM35DZ outputs a linear voltage between 0 and 5 volts relative to the temperature. The microcontroller to which the LM35DZ is attached performs an analog-to-digital conversion on this voltage, returning a value between -10 to 150 degrees Celsius. This information is displayed on the laptop screen. The LM35DZ is reported to have an accuracy within 0.5 degrees Celsius. The thermometer is mounted to the tip of the manipulator which, due to its rotation, makes it easy to collect temperatures from different angled vents.

3.8 Buoyancy Cartridge

Buoyancy for ROV *Competence* is essentially a simple block of foam. The vehicle is designed to hold this foam within the aluminum outer frame to keep it protected. The type of foam used is basic styrofoam, chosen for its workability, cost, and low density. To avoid the major flaw of styrofoam, its tendency to break apart into small particles in water, it is wrapped with Gorilla Tape. The volume of foam required was determined by attaching empty, plastic bottles until the vehicle was neutral; approximately five liters of displacement. The foam is shaped in such a way that it can be dropped in from above the vehicle and bolted to the frame. The foam was cut by a CNC mill with smooth angles to be hydrodynamic. To allow the buoyancy to be attached via a removable bolting system, it is glued to a thin sheet of polycarbonate. The whole buoyancy assembly is known as the "buoyancy cartridge" (see figure 3.14).

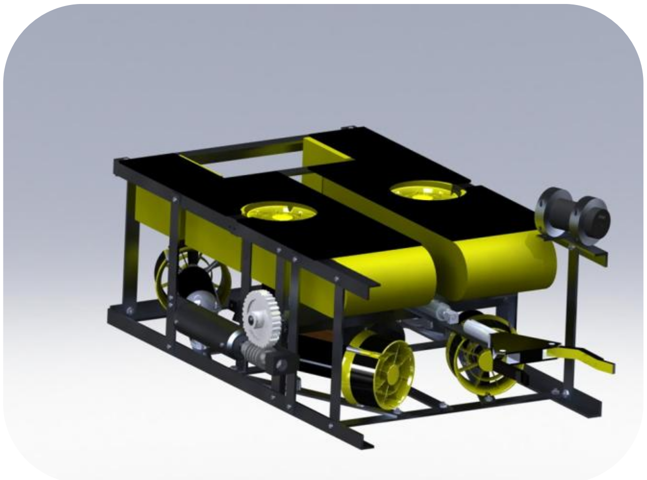

Figure 3.14 - Solidworks drawing of ROV Competence with its buoyancy cartridge in place

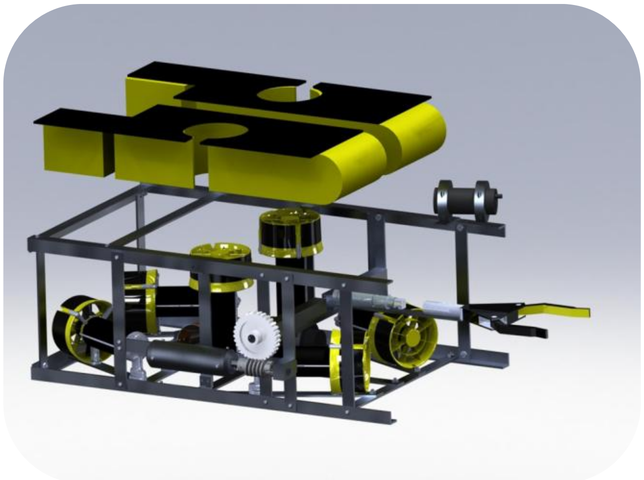

Figure 3.15 - Solidworks drawing showing ROV Competence's buoyancy cartridge being lowered in to the frame

3.9 Pneumatic Systems

ROV Competence has two systems powered by pneumatics; the manipulator and the agar deployment system (see corresponding sections in the report for more detail). The two options considered by the team for controlling these pneumatics were electronic solenoids and manual switch valves. The benefit of the solenoids was that the control of the pneumatics could be done by the Xbox controller, which means that one pilot could run the entire system easily. However, the team decided that the complexity and cost over manual switches was not worth the benefit.

To provide compressed air, the team originally chose to use a pressurized SCUBA tank. This was switched out with a compact Husky air compressor when the MATE competition rules changed to restrict SCUBA tank use. However, this compressor outperformed expectations, easily keeping up with the demands of the manipulator and agar deployment system without needing off-site refilling, as we would have had to do with a SCUBA tank.

Figure 3.16 - Compressor used to power pneumatics (courtesy of homedepot.com)

3.10 Tether

The tether contains power and ground cables for each of the seven motors (six thrusters and one manipulator rotation motor) on the vehicle, as well as three pneumatic lines for opening/closing the manipulator and positioning the agar collector. The tether also contains power, ground, and signal cables for the temperature sensor and audio signal cables for the microphone. There are also analog camera cables for our three cameras. The length of the tether is 20 meters long, a length limited by the camera cords but deemed satisfactory by the team for the mission. The whole tether is wrapped in a 'snake-skin' wrapping for ease of management and 15cm of foam every 30cm to make it neutrally buoyant.

4. Electronic Systems

4.1 Controls

ROV *Competence* is controlled by a Microsoft Xbox 360 wired controller which is connected to the base station laptop. The controller inputs are processed by the base station software. The Xbox 360 controller has two analog joysticks, two analog triggers, and ten buttons. ROV *Competence* uses the left analog joystick for x-y plane (surge and yaw) movement, the right joystick for z-plane movement (heave and roll), and the two buttons located on the shoulders of the controller to sway. The manipulator is rotated using the two analog triggers also located on the shoulders of the controller. See figure 2.1 for a detailed diagram of the controls.

Figure 4.1 - Diagram of system controls (Courtesy of Microsoft.com)

4.2 Base Station Software

The base station software is coded in Python, using the open-source pygame model to process controller inputs and display pertinent information to the screen. The pygame module translates movement on the analog sticks as a range from -1 to 1, and button presses as a 0 or 1. The software translates these inputs into a PWM duty cycle and direction for each thruster on the vehicle. The pyserial module, also available at no cost, is then utilized to send the duty cycles and direction data to the microcontroller at a rate of 9600 baud. The software also takes in temperature data in degrees Celsius from the serial line and displays it to the screen when there is new data available. In addition to the temperature data, the base station software records audio from the hydrophone every second and displays the frequency of the sample on the screen. The frequency is obtained by performing a Fast Fourier Transform on the audio sample using a function included in the SciPy module. The software is able to process the controller inputs such that it is possible to move in all axes of motion at the same time.

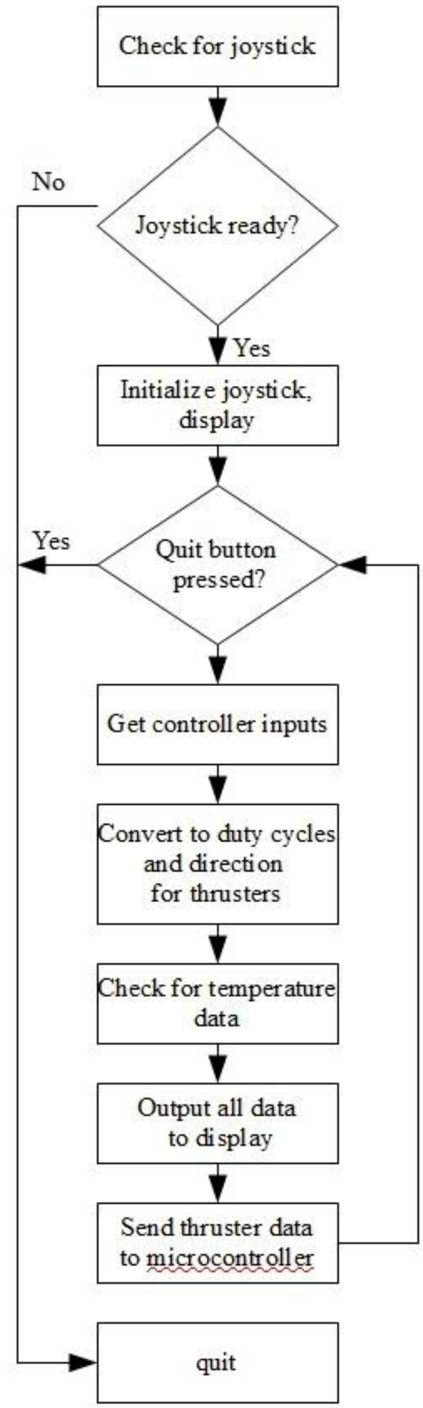

Figure 4.2 - Base station software flowchart

4.3 Microcontroller Software

The microcontroller used is an Arduino Mega board with an Atmega1280 chip. It has 14 PWM channels, seven of which are used to drive the thrusters, and 54 digital I/O pins, of which 14 are used to determine the direction of thrust for each thruster. There are also ten analog pins, of which one is used to obtain temperature data. Serial communication with the base station software is done through the FTDI USB-to-TTL serial chip on the board.

The software on the microcontroller sets the serial baud rate at 9600 baud, sets all the pins being used as output pins, and sets the PWM frequency at 7.8 kHz. The microcontroller will then continuously loop, receiving direction and duty cycle data from the base station and outputting this data on the correct pins (PWM channels 2-8, digital pins 40-53). The microcontroller also reads the temperature from the LM35DZ connected to analog pin 0 every second and sends this data to the base station. The software was written using the open-source Arduino processing language.

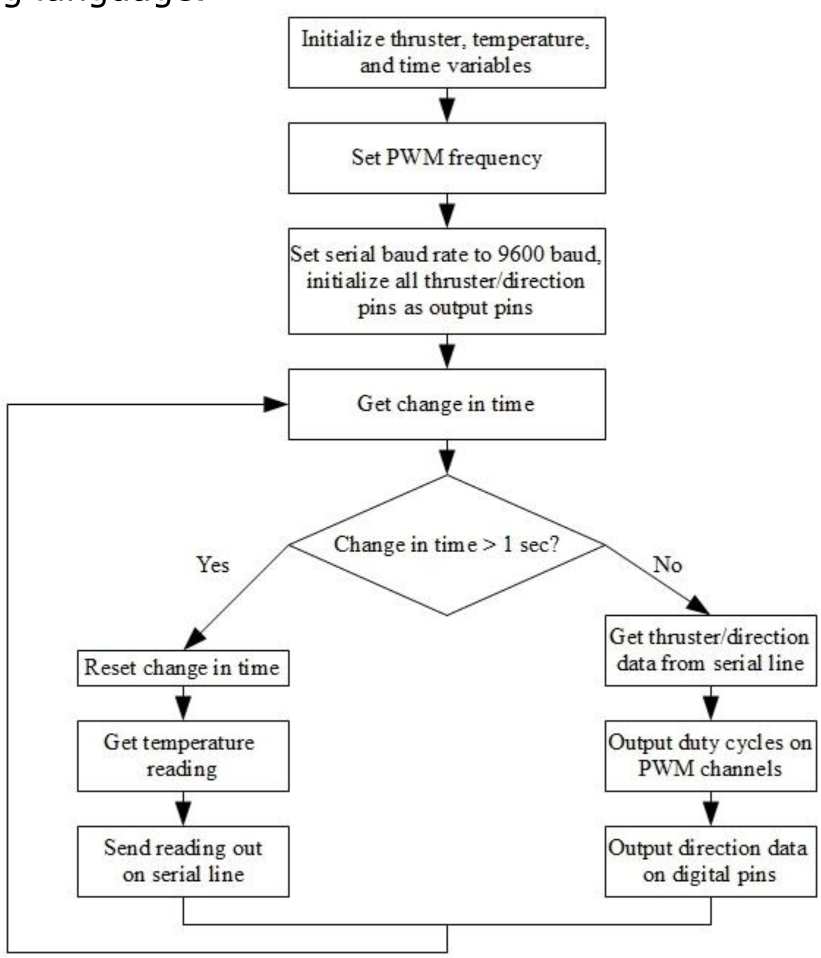

Figure 4.3 - Microcontroller software flowchart

4.4 Motor Controllers

The core of each motor controller is an STMicroelectronics VNH3SP30. The 3SP30 is an automotive grade, fully integrated h-bridge motor driver. Once the decision to utilize the Seabotix BTD-150 thrusters was made, it became clear what specifications for which the motor controllers needed to be designed. Knowledge gained was that the BTD-150 thruster was rated for 19.1Vdc at a max constant current of 4.25A. These specifications demonstrated that the VNH3SP30 would be a perfect fit for our application. With an absolute maximum input voltage of 40Vdc and a maximum throughput of 30A, it offered plenty of operating range, while being very flexible for use in future applications. There is one 3SP30 per motor to give the full independent control that was desired. Each 3SP30 driver interfaces with the Arduino Mega through a single pulse width modulation (PWM) pin, and two direction control pins. Based on the truth table of the two direction pins, the directions can be controlled as forward, reverse, or brake. The PWM allows the design to have variable motor speed. As the duty cycle of the input waveform increases, the 3SP30 increases the supplied power to the motor.

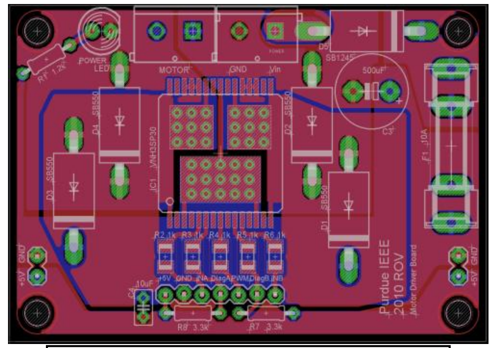

Figure 4.4 - Motor Driver Printed Circuit Board Layout

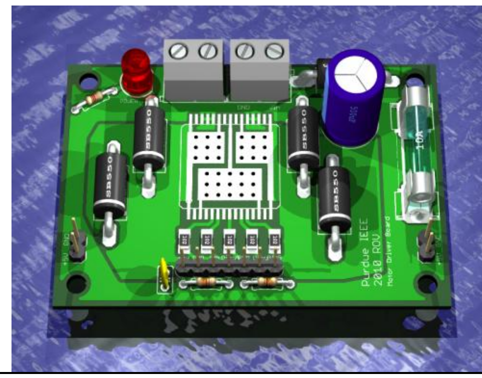

Figure 4.5 - Full Render of Motor Driver Printed Circuit Board (VNH3SP30 Excluded)

Since there is one 3SP30 per motor, the engineering decision was made to make individual driver boards for every motor. This allowed a single design that could be replicated seven times. This way, in the unfortunate instance that one board becomes damaged, it can simply be swapped out with another identical board. As the hope is to never have that happen, some protection on the boards themselves was implemented. For instance, each board has its own dedicated fuse which should save the board from any large surges in current. Just to be sure that there is power reaching the driver through the fuse, each board has a simple power indicator LED.

To help protect the 3SP30 and the motor, some simple passive components were put on the boards to help better manage the power. For sudden actions of the motor which cause large inrushes of current, moderately sized capacitors were added to supply an extra boost of energy. To protect from back emf generation from the motor, an array of power diodes were included to help clamp the voltage levels. If for some reason a large voltage was to be generated from the motor, these diodes would allow it to dissipate out.

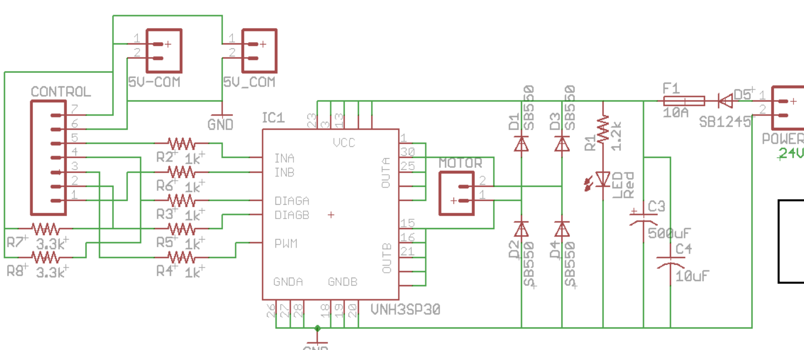

Figure 4.6 - Motor Driver Schematic

5. Reflection

5.1 Challenges

The ability to practice the mission was recognized by the team as a crucial part of its performance. In the state of Indiana, where Purdue is located, there are not many pools. Only one pool was found within a reasonable distance for frequent practice - Purdue University's own recreational center. While the facility has a very large pool and is indoors, both nice features for ROV practice, it was not a good option. The only time we would have been allowed to practice was after pool closing for the safety of other students, which left ten hours per week. Whenever we would practice, the facility also required us to hire one of their lifeguards to stand duty, costing $120 per practice session. Each practice session would also require a complete set-up and take-down of all mission props as the recreational center would not allow us to keep them there.

We resolved this issue by purchasing an above-ground pool. Based on SolidWorks drawings of the entire mission area, the minimum acceptable pool size was determined to be 5.5 meters in diameter. With nowhere to put it near campus, the pool was placed in Chicago, the city with the most teammates residing through the summer. A teammate volunteered to have this pool placed in his backyard where it is still being used for practice runs and killing the grass beneath it on a near-daily basis.

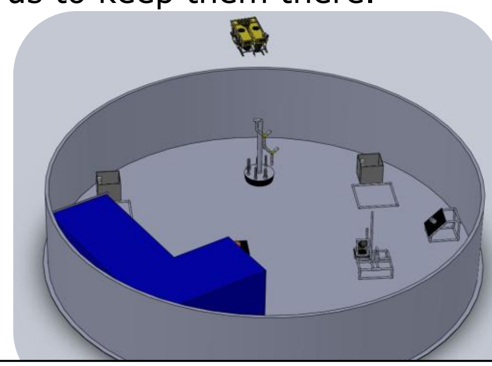

Figure 5.1 - Solidworks diagram of pool used for mission practice with mission props inside

5.2 Troubleshooting Techniques

Proper communication between teammates is key in solving complicated problems. With many people involved in the design and construction of the ROV and no periodic in-person meetings, the team knew an alternative form of communication was necessary. This is the purpose of the 'ROV Forum', an online forum where every aspect of the vehicle is discussed, debated, and voted upon. With over 250 posts and 21 topics between February and May of 2010, it has proved a great resource for making decisions.

A specific example of the forum in action as a troubleshooting technique was when it became obvious that the custom thrusters would not be ready in time. This post was made early on March 25th. In a 24 hour period, six replies were posted with possible alternatives and how they could be purchased. After a couple more days of discussion, one of the alternatives was chosen.

5.3 Future Improvements

There are many ways we feel we can improve ROV *Competence* in the future. For the past two years our electronics systems have been station-side, whereas it would better to place it on-board for signal reliability and tether size/weight reduction. We would also like to implement custom thrusters rather than commercial thrusters. We feel that doing this would allow us to achieve higher performance and weight/thrust ratio than commercial thrusters allow. While we do have one custom thruster being used for the manipulator system, it is our goal to use custom thrusters on the whole vehicle. Another issue we would like to improve upon is buoyancy. We have been using capped bottles and manually adjusting the water levels to maintain neutral buoyancy. In the future, we are going to move towards an adjustable buoyancy system controlled by the pilot.

5.4 Individual Reflections

Seth Baklor - Team Captain

This year marks a major advancement for the team I started for the 2009 competition. Last year, with just four dedicated team members and only myself having experienced the competition before, we knew the level of sophistication would need to be limited in order to finish on time. In addition, we started construction only a few weeks before the 2009 regionals. This year, however, is a different story. The design was agreed upon in early January with the construction starting soon thereafter. The 'ROV Forum' (see Troubleshooting Techniques) created an atmosphere where every team member could contribute equally. I was concerned, with only two returning team members and 13 new team members, that many might feel they could not contribute. However everyone did participate with most contributing well over 50 hours of work each throughout the semester. We now have a vehicle with greater power, better construction quality, and more reliable on-board tools through a more advanced design and incredible teamwork.

Clement Lan - Software Lead/Vice Captain

As the one in charge of writing the software for the controls and data processing, I had to utilize the skills I learned as a programmer and a computer engineer. I found this to be an excellent way to use my knowledge in a real-world application. I personally enjoyed writing and testing the software because it was relatively outside my scope of experience, which made it a challenge to research the options available to me. As the acting captain during the Fall semester, it was a challenge to recruit members and keep the team going because the rules didn't come out until late November, leaving almost a three month gap in which I had to figure out how to lead the team until December.

6. Expense Report

Table 6.1

Item	Expense (Cost $USD)	Income (Donation/Sponsorship)
ROV Construction		
Seabotix BTD150 (6)	$3,025.46	$3,000.00
Aluminum Bars, Angles, and Rod (Frame)	$100.49	
Use of Purdue Machine Shop (Frame Construction)	$132.00	
Nuts, Bolts, Washers (Frame)	$58.50	
Hose Clamps (Manipulator Mounting)	$18.59	
LCA-7700 Underwater Camera (2)	$816.00	
Vissior SC-420 Underwater Camera	$84.99	
Shaft Collers (Camera Mounting)	$33.64	
PikStik 'Grabber'	$24.99	
Binder-USA Double Acting Piston (2)	$22.15	
Passive Stereo Hydrophone	$52.00	
12Vdc In-Line Amplifier (Hydrophone)	$36.98	
Aluminum Mesh (Basket Construction)	$34.21	
Laptop (3 Years Old)	$500.00	
Arduino Mega Microcontroller Board	$64.95	
Motor Drivers (7)	$465.00	
Thermometer	$4.99	
Electrical Wiring for Tether (365 meters)	$142.00	
Pneumatic Line for Tether (60 meters)	$57.00	
Tether Wrap	$27.00	
Powerade & Thinq Bottles (Temporary Buoyancy)	$9.00	
Polycarbonate Sheet (Buoyancy Cartridge Cover)	$19.38	
Foam Block (Buoyancy Cartridge)	$15.29	
Husky Air Compressor (Pneumatic System)	$99.00	
Pneumatic Manual Switch Valves (2)	$42.29	
ROV Total	**$5,885.90**	

6. Expense Report (Continued)

Table 6.1

Travel/Competition		
Pool for Practice in Chicago	$405.00	
Set of Competition Props for Practice	$275.00	
Flights to Hawaii (5 Team Members)	$6,700.00	
Housing at the Competition	$900.00	
Checked Baggage Cost (ROV is considered baggage)	$150.00	
Travel/Competition Total	**$8,430.00**	
Donations		
Lockheed Martin		$1,000.00
Purdue Engineering Student Council		$3,000.00
IEEE, Purdue Chapter		$5,500.00
Team Member Donations		$851.14
Total	**$14,315.90**	**$13,351.14**
Leftover Funds from 2009		**$964.76**
	Balance	**$0.00**

7. Team Safety

From the beginning of construction, the team has been determined to be as safe as possible. OSHA approved safety goggles and closed toed shoes are required to be worn by all team members while power tools are in use. All power tools are connected through a surge protector that is switched off whenever a tool is not in use.

ROV *Competence's* design includes few components that could be dangerous to itself, a user, or the environment. The six onboard motors are all fitted with plastic propellers that pose less of a threat than metal propellers and are enclosed in a protective shroud. All motors are protected within the main frame.

Figure 7.1 - Safety glasses (courtesy of amazon.com)

Figure 7.2 - Propeller (courtesy of amazon.com)

Figure 7.2 - Electrical warning (courtesy of 4candles.co.uk)

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List of acronyms used in this Technical Report

MATE - Marine Advanced Technology Education Center
ROV - Remotely Operated Vehicle
IEEE - Institute of Electrical and Electronics Engineers
HUGO - Hawai'i Undersea Geo-Observatory
HURL - Hawai'i Undersea Research Laboratory
PESC - Purdue Engineering Student Council
HRH - High-Rate Hydrophone
CAD - Computer Aided Design
CNC - Computed Numerically Controlled
PWM - Pulse Width Modulation

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