University of Houston

Team Azul

ROV

B.O.S.S.

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Abstract

The following report presents Team AZULs aim at designing and building an underwater Remotely Operated Vehicle (ROV) to compete in the 2011 MATE International ROV competition, with the goal of creating an industry-viable hybrid vehicle. This project will help Team AZUL explore the use of an ROV for collegiate competition and industry use.

Introduction

TeamAZUL

Team AZUL consists of Joel Vazquez (Team Leader), Salah Ahmad, Walter Turner, and Luke Herranen. Each member adds great value to the team: Joel initiated the project and serves as team leader. Salahcontributes his experience fromthe marine industry to the team. Walter is the public relations master of the group. Luke brings his knowledge and skills ofelectronics and control systems.

Group Photo (Left to Right: Vazques, Ahmad, Turner, Herranen)

ROV History

The first tethered underwater Remotely Operated Vehicle (ROV) was invented in 1953 by DimitriRibikoff. The United States Navy played the leading role in ROV technology development in the 1960's and 1970's. The U.S. Navy used ROV's to find sunken ordinance from the oceans. A critical task performed by a U.S. Navy ROV was to locate and recover a nuclear warhead that was on the sea floor, due to a plane crash in 1966. After the U.S. Navy invested in and developed their ROV program, the oil and gas industry invested heavily in ROV technology and used itin subsea installations and inspections. Today about 85% of ROVs are used by the oil & gas industry. A declining economy and declining oil prices in the 1980's led to a decrease in investments in ROV technologies and subsequently in development. In the 1990's,rising oil prices and upbeat economy again revived ROV technologies. Today's ROVs are mainly used in the oil and gas industry,telecommunications, and science and research. They are progressing to operate at deeper depths to offer safe and cost effective intervention.

ROV Background

The four basic classes of ROVs are work class, general class, mini class, and micro class. The work class ROV is generally a large ROV that is larger than 6 feet in all dimensions(LxWxH) and works in depths of up to 6000 meters. The work class ROV is used in the Oil and Gas industry for subsea installations, maintenance, inspection and other under water activities. The general class ROV's are smaller and used to go to places where a work class ROV cannot fit or is not practical for one to work in. A general class ROV is used for subsea inspection of pipelines, oil rigs as well as mapping sea floors and recovering lost objects. The mini and micro class ROV's are used mainly for scientific research and data collection.

Team AZUL Goal

The Goal for Team AZUL is to design and build a hybrid ROV: an industry-viable modular design and with which we can also participate in the 2011 MATE competition.

MATE 2011

Design specifications of MATE 2010 were followed till the 2011 competition specs were published on Dec 4, 2010. They include:

1. Simulate cutting the damaged riser pipe.
2. Remove the damaged riser.
3. Cap the oil well.
4. Collect water samples and measure depth.
5. Collect biological samples.
6. Vehicles to operate at 40 feet depth.

ROV Principles

Structure

The frame of any unit is the backbone and provides the strength of any project. When it comes to ROV's we first start off with the chassis. The chassis in work class ROV's are made of aluminum. OtherROV's are made of different materials such as: plastics, steel, and other composites. TeamAZUL's ROV is built with HDPE and offers a strong yet lightweight material to build with. Please see Picture 1 below:

Picture1

Buoyancy

The success of any underwater endeavor rests on buoyancy. There are three different kinds of buoyancy. Negative buoyancy is when the object simply sinks to the bottom. Positive buoyancy is when an object tends to float and has a hard time sinking. Neutral buoyancy is when an object stays in place at a certain depth. Team AZUL would like to design a unit that has a slightly positive to neutral buoyancy factor. This will help at the sea bottom, by avoiding stirring up silt when the vehicle wants to come up. Also, if the ROV is ever cut loose, it ensures that it will eventually float to the surface.

The ROV is being designed to operate at 65 feet, but will be built to safely overcome depths of 100 feet. This would mean that it has to withstand 43.3 pounds per square inch:

Pressure = **rgh=** 1000kg/m³ x 9.81m/s² x 30.48m

Pressure = 299009Pa ≈ 43.3 psi

Buoyancy is the tendency of a fluid to exert a supporting force (Buoyant Force) on a body place in the fluid. The equation for the Buoyant Force is:

$$F_b = g_f V_d$$

F_b Buoyant Force

g_f Specific Weight

V_d Volume of fluid being Displaced by the object

Weight of the object must be calculated to know whether an object will sink or float:

$$W_o = m_o g$$

W_o= weightof the object

m_o= mass of the object

g = gravitational acceleration

To link Buoyancy Force equation to the Weight of the Object we need to have the Specific Weight equation. Specific Weight of Fluid:

$$g_f = r_f\, g$$

g_f = Specific Weight

r_f=density of fluid

g = gravitational acceleration

The density equation is:

$$\mathbf{r} = \frac{\mathbf{m}}{\mathbf{V}}$$

Submarines and scuba divers depend on Neutral buoyancy to control their depth. Neutral Buoyancy is achieved when the weight of the body is exactly the same as the weight of the volume of the fluid displaced. To achieve neutral buoyancy:

$$\mathbf{W_o = F_b}$$

Therefore: $\mathbf{m_o g = g_f V_d}$

Equation of Density: $\mathbf{r = \frac{m}{V}}$

Result is: $\mathbf{m_o g = \frac{m}{V} V_d g}$

Canceling out leaves: $\mathbf{m_o = m_f}$

The mass of the object must equal the mass of the fluid that it displaces to achieve neutral buoyancy. However, for the Team Azul's ROV, and most underwater vehicles of this nature, positive buoyancy is desired. This is in-case the vehicle comes undone from its tether, it would safely float to the surface and also the vehicle would not have to use its thrusters lifting from the sea floor, stirring silt.

Team Azul's ROV has the following buoyancy numbers displayed in **Figure 1** below with the following stats:

F_{Bf}= 119.93 N
F_{Be}= 20.25 N per enclosure
F_F= -129.63 N
F_M= -4.05 N per motor
F_E= -10 N per enclosure

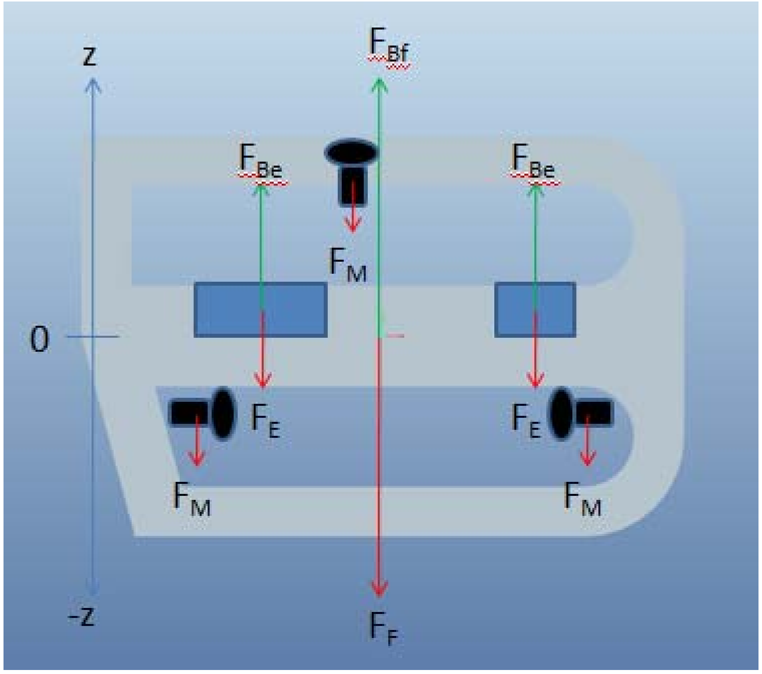


Figure 1

Thrusters

An ROV needs to be able to move around underwater, and for that we need propellers (often called thrusters) which in turn need motors to drive them. The choice of motor, and how we are to control them, is key to the design of the propulsion system. Team AZULwas given/donated 3 Seabotix BTD150 thrusters which have 18 N thrust each. We have planned for 4 thrusters in the horizontal plane and 1 in the vertical. This is approximately ¼ of our total power supply from the surface. This decision was made within the restrictions of using power between propulsion, video lights, sensors, and manipulator while still having a safety factori.e. so the electronics do not overheat etc. Please see Picture 2 of thruster below:

Picture 2

Electronics

When it comes to ROVs, one of the most important areas is the electronics and understanding its functions. The tether is the umbilical cord of the system, where all the information travels from topside controllers on the surface to the bottom-side ROV. Inside of a tether are wires that carry power, data, and different signals to and from the control center. If the tether would ever detach the ROV would be in danger of being lost or damaged and is thus an area that requires great care in design and implementation.

Next is the control systems, this area consist of several different components such asthe circuit board and microprocessor etc. ROVs can have onboard control systems to manage different electrical areas.

The video output and control interface are also areas of great importance due to the fact that programming is required. The underwater camera and lighting must work together and one without the other is useless. Team AZUL has dedicated the limited surface power in such a way. Pls. See Table 1 below:

System	Power (Watts) =IV	Total 1920 (Watts)
Thrusters	410	
Electronics/Tools	420	
Manipulator	350	
Video lights	100	
Camera	140	
Safety Factor		500

Table 1

Tools

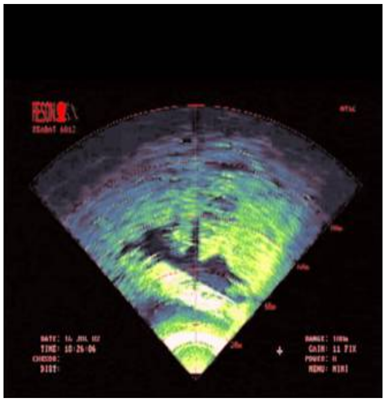
ROVs can have the ability to complete different task that in some cases might be impossible for humans to do. ROVs are known to have several tools onboard for various applications. Team Azul, with its modular design, is built as to add various sensing equipment.

Sonar is very popular as it can be used to map the seafloor in order to find lost items and also serve as a second set of eyes for the ROV in case visibility is reduced, making the onboard camera system deficient. (Pls. see Picture 3 for sample sonographic image representing a broken ship on the seafloor.)

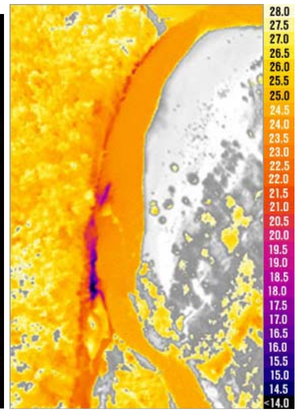
Metal detection is also very helpful as it can be used to follow a pipeline that might be buried in the ground for inspection. A magnetometer is a scientific instrument used to measure the strength and/or direction of the magnetic field in the vicinity of the instrument. These devices can greatly aid in locating lost tools and undersea items for the ROV. Team Azul is using a simple version of this tool in its modular design to assist with ROV instrumentation capabilities. Port # 9 has been assigned to transmit the information to the ROV processor for this task.

An Infrared Radiometer is used to sense thermal differences on the seafloor bottom. This instrument can give the ability of locating anything with a heat signature underwater such as a leaking oil pipeline and operating machinery. (Pls. see Picture 4 of a leaking oil pipeline underwater.)

Team Azul, as of Dec 5, 2010 has only been able to acquire a magnetometerand is still talking to different vendors met at the MTS meeting on Oct 28, 2010 to gain other sensor packages.



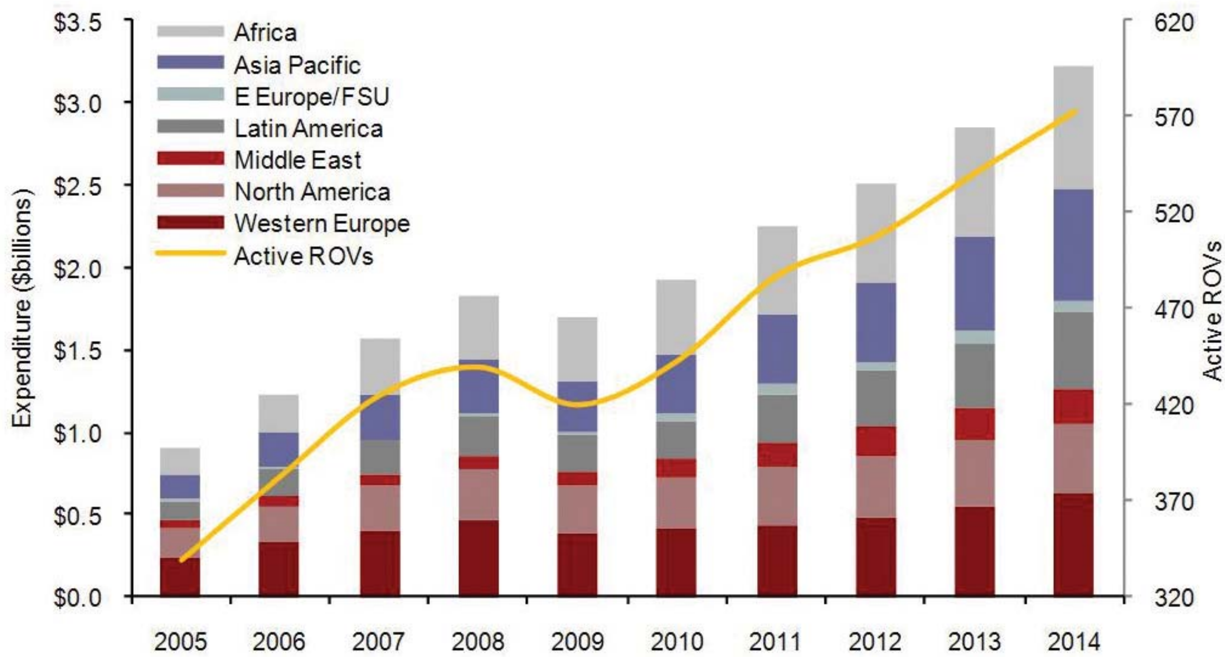
Picture 3



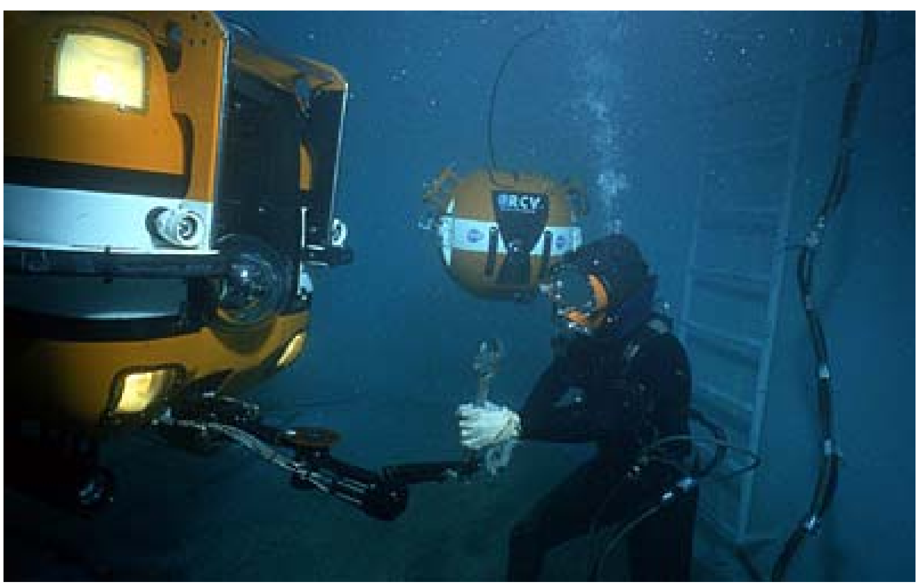
Picture 4

ROV Markets

The primary market for ROVs is in the offshore Oil and Gas industry, roughly 85% of the market. Telecommunications, who have 14% market share, mainly employing ROVs to assist in the laying of trans-oceanic cable. Scientific and academic research, though it is the public's primary exposure to ROVs, makes up less than 1% of the market. The market for ROV's is rapidly growing. According to the Douglass-Westwood industry report, "the attrition of the existing fleet will require over 550 new work-class units over the next five years – driven by the industry's push into deepwater and the increased necessity of work-class ROVs in today'sindustry." Please see Graph 1 below to understand the growing ROV market.



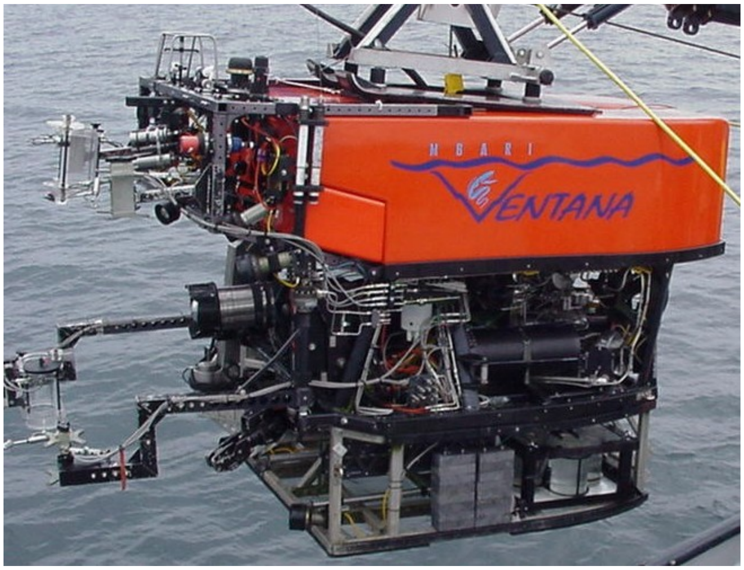
Graph 1



Picture 5

Class Distinctions

General-class ROVs are usually one to two feet in width and height and generally two to three feet long. The most common thruster configuration is four horizontal and one vertical, all fixed. They are primarily used for inspection of offshore structures as well as diver aid. However, they can be used in many cases for light work and some heavy work with certain payloads or attachments. This class is a popular size for science and research, as it is capable of carrying a sizeable payload while still retaining the inherent efficiency of a fully-electric ROV design. (Please see Picture 5above &Picture 6 below)



Picture 6

Commercial Designs

There are two main commercial designs that Team AZUL's ROV is comparable to: the Seaeye Falcon and the Sub-Atlantic Mohawk. (Please see Picture 4 & 5) The Falcon measures 1.6 feet high, 2 feet wide, and 3.2 feet long. It weighs 110 pounds with a 19-pound payload, can dive to 980 feet, and its frame is polypropylene. It is also equipped with a single-function manipulator and can field a five-function manipulator as an additional payload. The Mohawk is similar in size to the Falcon (2 ft x 2.5 ft x 3.1 ft), but due to its traditional construction and aluminum frame weighs 364 pounds. This additional weight translates into a heavier payload capacity at 77 pounds. A manipulator is not included in the basic design but can be added via a tool skid. The Mohawk can dive to 3,280 feet. Another design to be considered was constructed privately by one Ed Jacobs. Similar in specification to the Falcon and with a reduced dive depth of 300 feet, it is a fraction of the cost. Close inspection of this design will hopefully lower the team's price point.   Please see Picture7 below.

Picture 7

Price Ranges

"Mini"-class observation ROVs run from $5,000 to $10,000, but their capabilities are limited by their small size. Larger observation ROVs (in the general-class range) are manufactured with a hydrodynamic shell and have the ability to cover an exceedingly large area of ocean. However, because their advanced design, they are also extremely expensive - $55,000 to $500,000 without options. The general class ROVs described above are $125,000 and $100,000 for the Falcon and Mohawk, respectively. The "Jacobs" ROV is only $5,000, and it is because of this design's compromise between features and affordability that our budget is approximately $20,000.

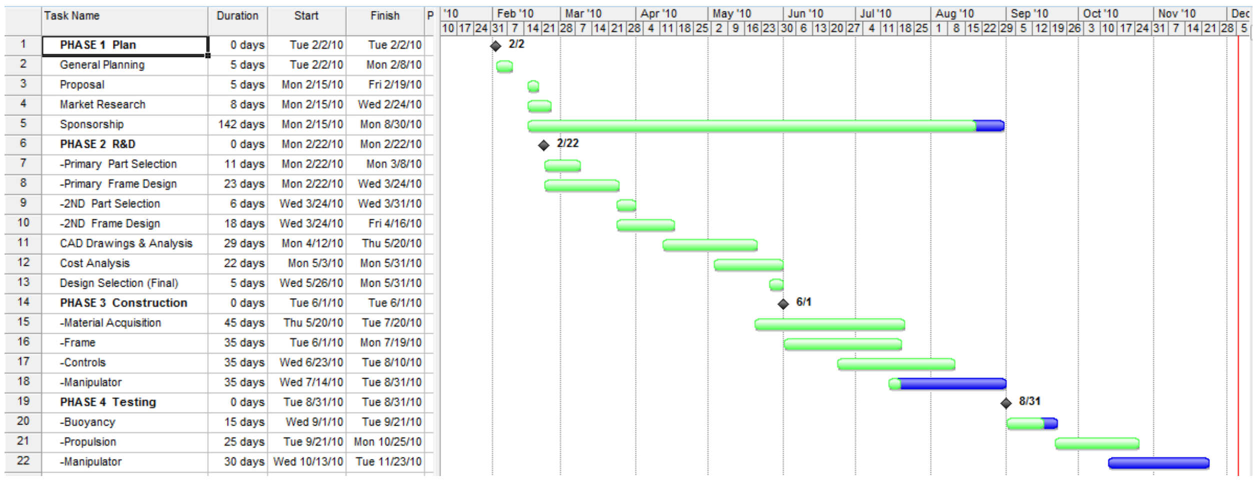
Scope

Scope of Work

Team AZUL's goal is to make a hybrid ROV; one with which Team Azul can enter the MATE competition in June 2011 and then use it in commercial applications. The ROV is being designed and built to exceed competition requirements. The team is designing an ROV that would be a ‘modular' in design, in which one is able to add/subtract parts easily, such as an infrared radiometer, which would give the ROV a dual purpose. This type of multi-usage will present challenges in such a project, along with lack of knowledge about the 2011 MATE requirements, because they have been published much after the team has designed and built its ROV. The team carefully looked over past requirements and guessed that a 3 axis of motion spatially controlled arm would be required to be built versus a rate manipulator arm -the difference is that the first responds in real time to master control whereas the second only responds to on/off commands in a given axis. However, due to funding limits and a change in the MATE competition requirements, no such arm was built; instead, a host of ‘finger’ tools were designed to deal with the upcoming specifications. If the vehicle is grounded or the object that it was trying to retrieve, the ROV will be physically pulled out of the water (with the object attached) by its reinforced tether. The ROV will also encompass a number of sensors for leak detection, sonar, and metal detection and vendors will be actively pursued for donations.

Gantt Chart

Our Gantt Chart at this point is fairly straight-forward and simple. We have three stages of which the first one is Planning. The second stage is research & development which includes frame design and analysis. Designing and testing along with fundraising and material finalization, was set to be completed by June 1. However, due to financial restraints and poor fundraising in down economy, Team Azul was unable to meet its financial targets. The ROV specifications needed to be finalized by this date so production could start, and this delay has caused all other tasks to be postponed. At the time of writing this report, Dec 5, 2010 our design is 100% complete and we have built the prototype and final version of the ROV. The final design of the vehicle is complete with only minor ‘tweaking’ needed. During the summer, Team AZUL was able to work heavily on the control/electrical systems of the ROV. This work, often difficult, because of the lack of understanding mechanical engineers have in electrical aspects, was still completed due to great overall team effort. The manipulator arm was never fully designed or worked on due to budget constraints. This may have been a blessing in disguise because the MATE 2011 competition does not require a manipulator arm, only non-movable tools such as a grip and saw. However, one is still planned to be designed and built to pursue the commercial aspect of the ROV. Final submission of the project, including a completed report, is scheduled for December 7, 2010.



	Task Name	Duration	Start	Finish
1	**PHASE 1 Plan**	0 days	Tue 2/2/10	Tue 2/2/10
2	General Planning	5 days	Tue 2/2/10	Mon 2/8/10
3	Proposal	5 days	Mon 2/15/10	Fri 2/19/10
4	Market Research	8 days	Mon 2/15/10	Wed 2/24/10
5	Sponsorship	142 days	Mon 2/15/10	Mon 8/30/10
6	**PHASE 2 R&D**	0 days	Mon 2/22/10	Mon 2/22/10
7	-Primary Part Selection	11 days	Mon 2/22/10	Mon 3/8/10
8	-Primary Frame Design	23 days	Mon 2/22/10	Wed 3/24/10
9	-2ND Part Selection	6 days	Wed 3/24/10	Wed 3/31/10
10	-2ND Frame Design	18 days	Wed 3/24/10	Fri 4/16/10
11	CAD Drawings & Analysis	29 days	Mon 4/12/10	Thu 5/20/10
12	Cost Analysis	22 days	Mon 5/3/10	Mon 5/31/10
13	Design Selection (Final)	5 days	Wed 5/26/10	Mon 5/31/10
14	**PHASE 3 Construction**	0 days	Tue 6/1/10	Tue 6/1/10
15	-Material Acquisition	45 days	Thu 5/20/10	Tue 7/20/10
16	-Frame	35 days	Tue 6/1/10	Mon 7/19/10
17	-Controls	35 days	Wed 6/23/10	Tue 8/10/10
18	-Manipulator	35 days	Wed 7/14/10	Tue 8/31/10
19	**PHASE 4 Testing**	0 days	Tue 8/31/10	Tue 8/31/10
20	-Buoyancy	15 days	Wed 9/1/10	Tue 9/21/10
21	-Propulsion	25 days	Tue 9/21/10	Mon 10/25/10
22	-Manipulator	30 days	Wed 10/13/10	Tue 11/23/10

Past Issues

Team AZUL carefully looked at what other teams had done and where they failed. This was done to develop a winning strategy by avoiding previous pot-holes. One of the very first things we studied as a team was potential pitfalls. Team AZUL found out that, in the past, mechanical engineers have had many problems with the electrical control aspect of the ROV, such as overloading the control systems –this was validated this summer when the team was building the control systems. Also, another team that entered the MATE competition with a perfectly running ROV was unable to sink down to the bottom due to excessive positive buoyancy. This inability of the ROV to sink forced the team out of the competition. Some of the critical issues that can prevent Team AZUL from entering into competition are electrical, buoyancy, and team management issues that have plagued previous teams.

Risk Analysis

A preliminary risk assessment was done by Team AZUL to see what potential problems we could plan for. A Risk Analysis template was found at the McCombs School of Business for a feasibility study done on an aircraft project. The format used helped us identify many internal and external threats and then helped us assess the risk associated with them. One of the first areas the team assessed was External Risk; this is defined as what factors damage or delay the project. For Team AZUL, advice, parts, and fundraising were from outside sources and thus posed potential threats. With such important considerations as parts and advice being dependent on outside sources, Team AZUL still considered these low threat or risk factors, arguing that if one supplier or advisor failed another could always be found. Fundraising was also deemed a low threat, given the extensive presence of the offshore oil and gas industry in Houston. This concept would be hard to appreciate, and we expected skepticism from our audience during the presentation. (This topic will be more thoroughly discussed in Fundraising.) Also, our Management Risk is extremely high because any project will fail (and many have) due to this inability. Our overall risk assessment is scored at 7 out of 10 which is High risk project.

Budget

A preliminary budget was developed which shows the costs of necessary parts and travel for the MATE competition. This budget considers the various goals Team AZUL is trying to achieve. Some of the items/materials are essential to building and operating the ROV (listed in yellow) such as thrusters and tether. Others items, such as radiometer and sonar are parts that Team Azul requires to make this vehicle commercially viable, but not necessarily vital. The total budget was estimated to be $15,000 (Please see Budget 1) some of which is collected through materials or donations.

Estimated Cost of Specification			
Items	Quantity	Estimated Cost ($)	Donations ($)
Thrusters	5	2500	1500
Tether	1	900	900
Control System (PLC)	1	1500	1000
Material	1	1000	500
Camera	2	2000	
Coating/Paint	1	600	
Manipulator	1	1200	
Infrared Radiometer	1	800	
Metal Detector	1	500	
Lights	4	1000	
Travel	4	2000	
Sonar	1	600	
Other	1	400	
TOTAL		$15,000	$3600

Budget 1

As of Dec. 5, 2010 our budget and donations stand at much different amounts than anticipated. This may be due to the weak economy where vendors are less likely to contribute due to their bottom-line. We initially had very positive results from companies such as Oceaneering and Schilling Robotics, but these initial contacts were reluctant to pursue any grants. However, thanks to Exclusive Wireless and SI Technologies we were able to cover the shortfall in funding and our budget stands as the following. Some of the donations were used in purchasing parts again to cover mistakes in design, such as in having to purchase an additional Aduino CPU because the initial one could not handle the load. Other items had to be purchased again, such as the electronic boxes because of our repeated mistakes in drilling watertight seals. Please see Budget 2 table for financial details.

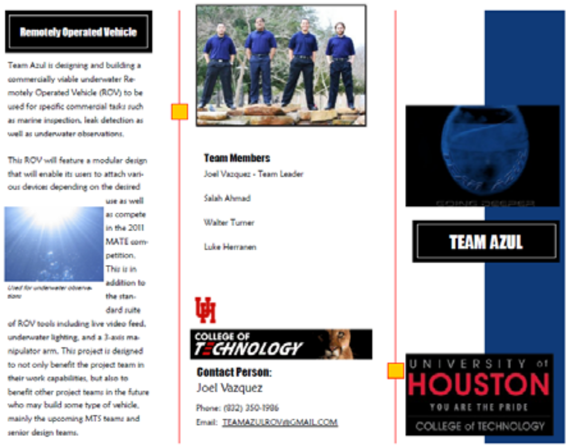
Items	Quantity	Cost $
Thrusters	5	2500
Tether	1	900
Control System (PLC)	1	725
Frame Material	2	320
Camera	2	270
Building Material		360
Power Supply		110
Coating/Paint	1	200
Arm	1	500
Infrared Radiometer	1	800
Metal Detector	1	300
Sonar	1	600
Total Cost ($)		7585
Donations (Money)	2500	
Donations (Parts)	2985	
Still Needed ($)		2100

Budget 2

Team Azul will have to vigorously pursue funding to make up for the shortfall in the budget. $2100 are still needed to purchase the sensing equipment needed to make the ROV truly commercially-viable.

Funding Strategy

Initially, Team Azul was contacting the larger offshore industries such as Halliburton and Shell to acquire funds for the project. After receiving a lukewarm response and failing to raise any funds in a three month period, we decided to target small to mid-size businesses. A brochure was developed to present to these companies. (Please see Brochure 1 below.) With these brochures and the new initiative to contact local companies versus larger more inaccessible ones, and involve them with the College of Technology, Team Azul was able to immediately raise $1500. This strategy has returned much better results in the short time it has been used.



Remotely Operated Vehicle

Team Azul is designing and building a commercially viable underwater Remotely Operated Vehicle (ROV) to be used for specific commercial tasks such as marine inspection, leak detection as well as underwater observations.

This ROV will feature a modular design that will enable its users to attach various devices depending on the desired use as well as compete in the 2011 MATE competition. This is in addition to the standard suite of ROV tools including live video feed, underwater lighting, and a 3-axis manipulator arm. This project is designed to not only benefit the project team in their work capabilities, but also to benefit other project teams in the future who may build some type of vehicle, mainly the upcoming MTS teams and senior design teams.

Used for underwater observations

Team Members

Joel Vazquez - Team Leader

Salah Ahmad

Walter Turner

Luke Herranen

COLLEGE OF TECHNOLOGY

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TEAM AZUL

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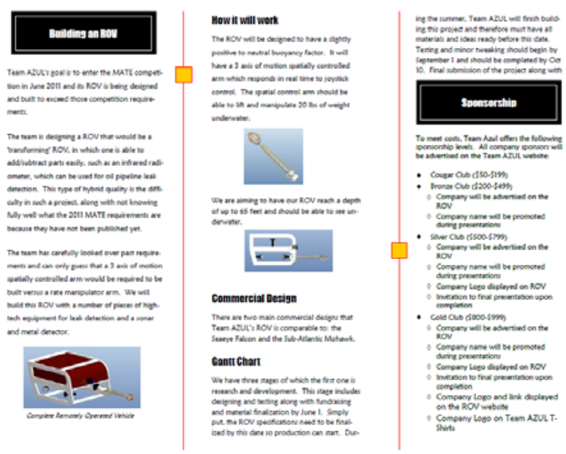


Building an ROV

Team AZUL's goal is to enter the MATE competition in June 2011 and its ROV is being designed and built to exceed those competition requirements.

The team is designing a ROV that would be a 'transforming' ROV, in which one is able to add/subtract parts easily, such as an infrared radiometer, which can be used for oil pipeline leak detection. This type of hybrid quality is the difficulty in such a project, along with not knowing fully well what the 2011 MATE requirements are because they have not been published yet.

The team has carefully looked over past requirements and can only guess that a 3 axis of motion spatially controlled arm would be required to be built versus a rate manipulator arm. We will build this ROV with a number of pieces of high-tech equipment for leak detection and a sonar and metal detector.

Complete Remotely Operated Vehicle

How it will work

The ROV will be designed to have a slightly positive to neutral buoyancy factor. It will have a 3 axis of motion spatially controlled arm which responds in real time to joystick control. The spatial control arm should be able to lift and manipulate 20 lbs of weight underwater.

We are aiming to have our ROV reach a depth of up to 65 feet and should be able to see underwater.

Commercial Design

There are two main commercial designs that Team AZUL's ROV is comparable to: the Seaeye Falcon and the Sub-Atlantic Mohawk.

Gantt Chart

We have three stages of which the first one is research and development. This stage includes designing and testing along with fundraising and material finalization by June 1. Simply put, the ROV specifications need to be finalized by this date so production can start. During the summer, Team AZUL will finish building this project and therefore must have all materials and ideas ready before this date. Testing and minor tweaking should begin by September 1 and should be completed by Oct 10. Final submission of the project along with

Sponsorship

To meet costs, Team Azul offers the following sponsorship levels. All company sponsors will be advertised on the Team AZUL website:

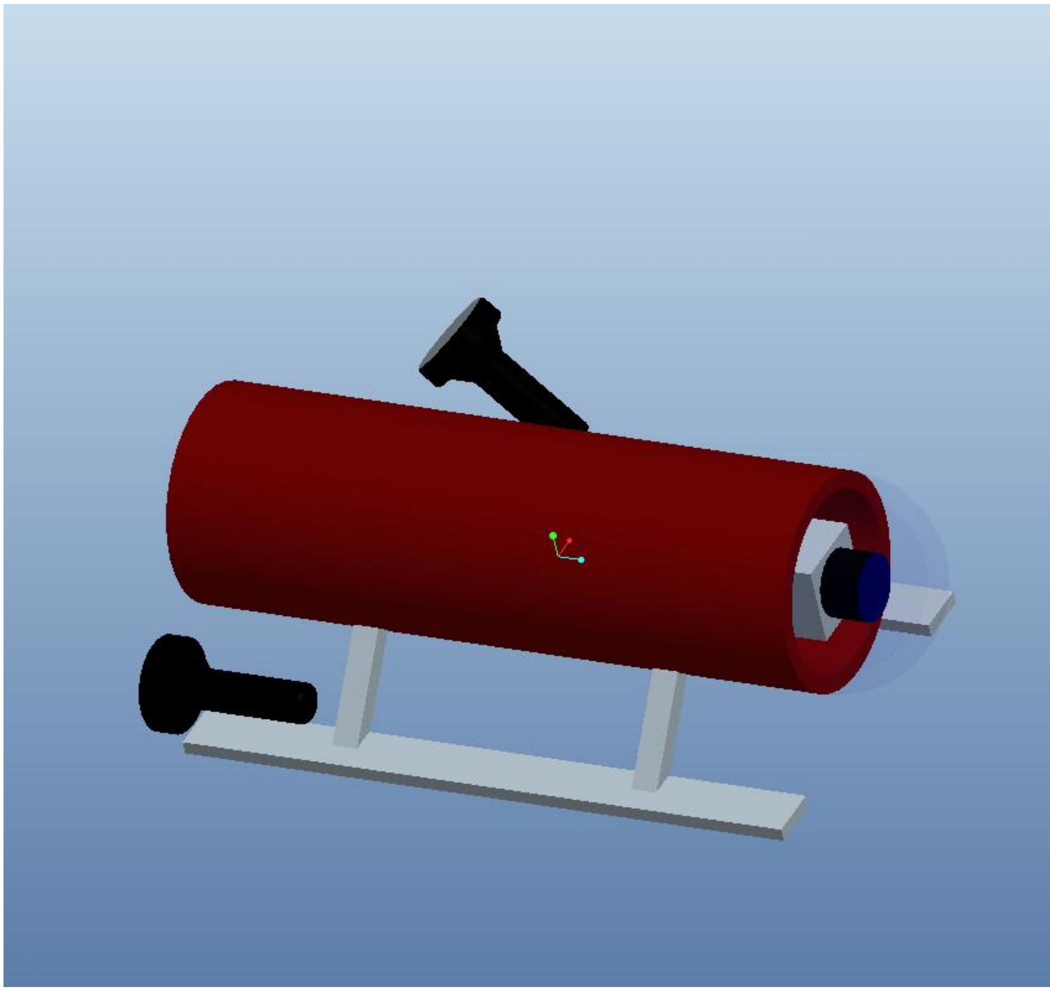
- Cougar Club ($50-$199)
- Bronze Club ($200-$499)
  - Company will be advertised on the ROV
  - Company name will be promoted during presentations
- Silver Club ($500-$799)
  - Company will be advertised on the ROV
  - Company name will be promoted during presentations
  - Company Logo displayed on ROV
  - Invitation to final presentation upon completion
- Gold Club ($800-$999)
  - Company will be advertised on the ROV
  - Company name will be promoted during presentations
  - Company Logo displayed on ROV
  - Invitation to final presentation upon completion
  - Company Logo and link displayed on the ROV website
  - Company Logo on Team AZUL T-Shirts

Brochure 1

Design Analysis

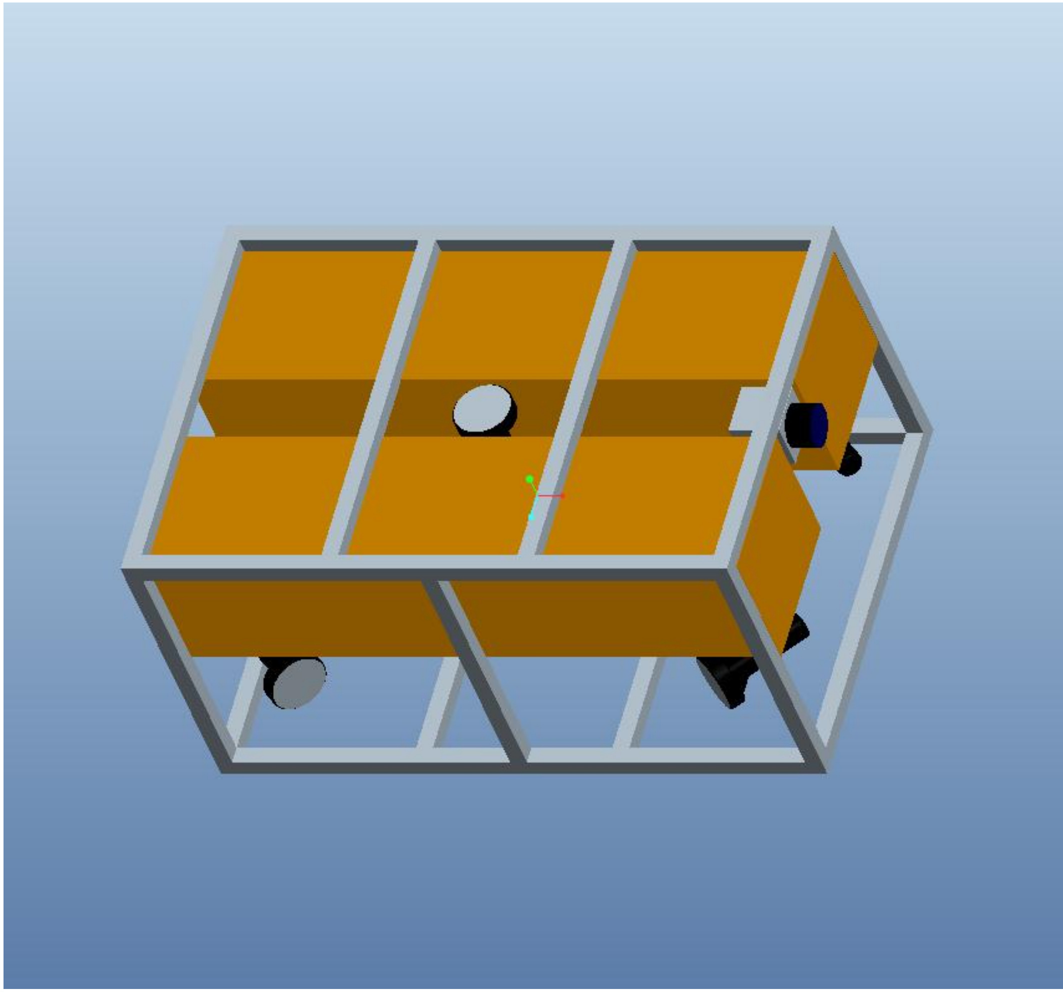
Frame Design Comparison

Three designs were considered, and they are described below.



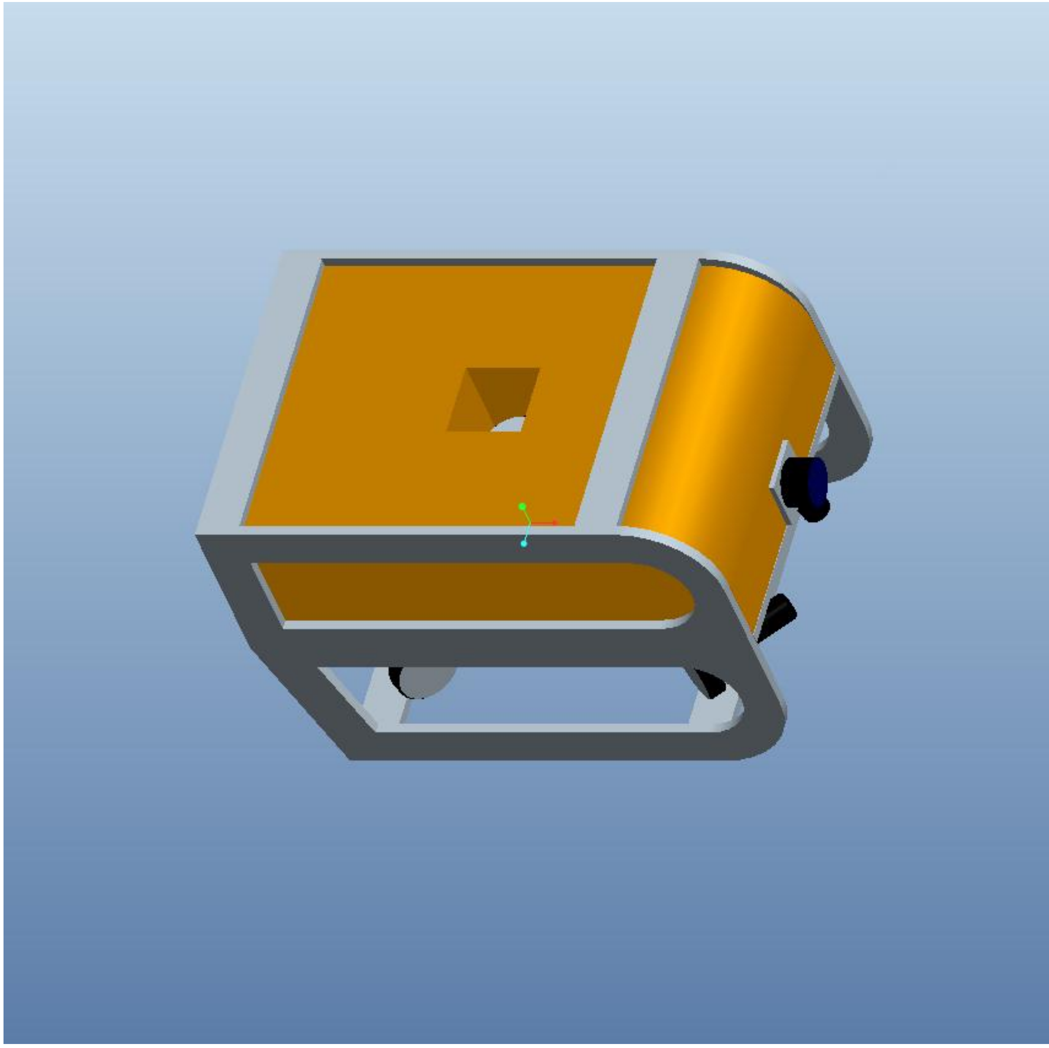
Design A

Design A was the first design considered; it is a typical mini-class ROV. All electronics and drive circuits are encased in a plastic enclosure extending the length of the vehicle, with thrusters mounted to the outside. A 3-thruster configuration, design A would use two thrusters for forward/reverse propulsion, mounted on the skids, with a third thruster mounted at 45 degrees to the vertical to facilitate movement up and down in the water column. While this streamlined design would provide exceptional speed and low drag, maneuverability is compromised by the thruster configuration. Also, there is little room for expansion or additional equipment, which is incompatible with the main goal of Team Azul to provide a multi-purpose hybrid platform.



Design B

Design B was the next iteration in Team Azul'sdesign process. This larger ROV incorporates many more elements of the general-class design, and the open frame offers additional versatility. Unfortunately, this frame was designed with aluminum or steel in mind, and thus is joined by welds. Due to the size of the frame, coupled with the densities of the aforementioned substances, it was decided that thermoplastics would be a much better alternative. This design would not be feasible without an extraordinary amount of epoxy to glue together the ¾" members.

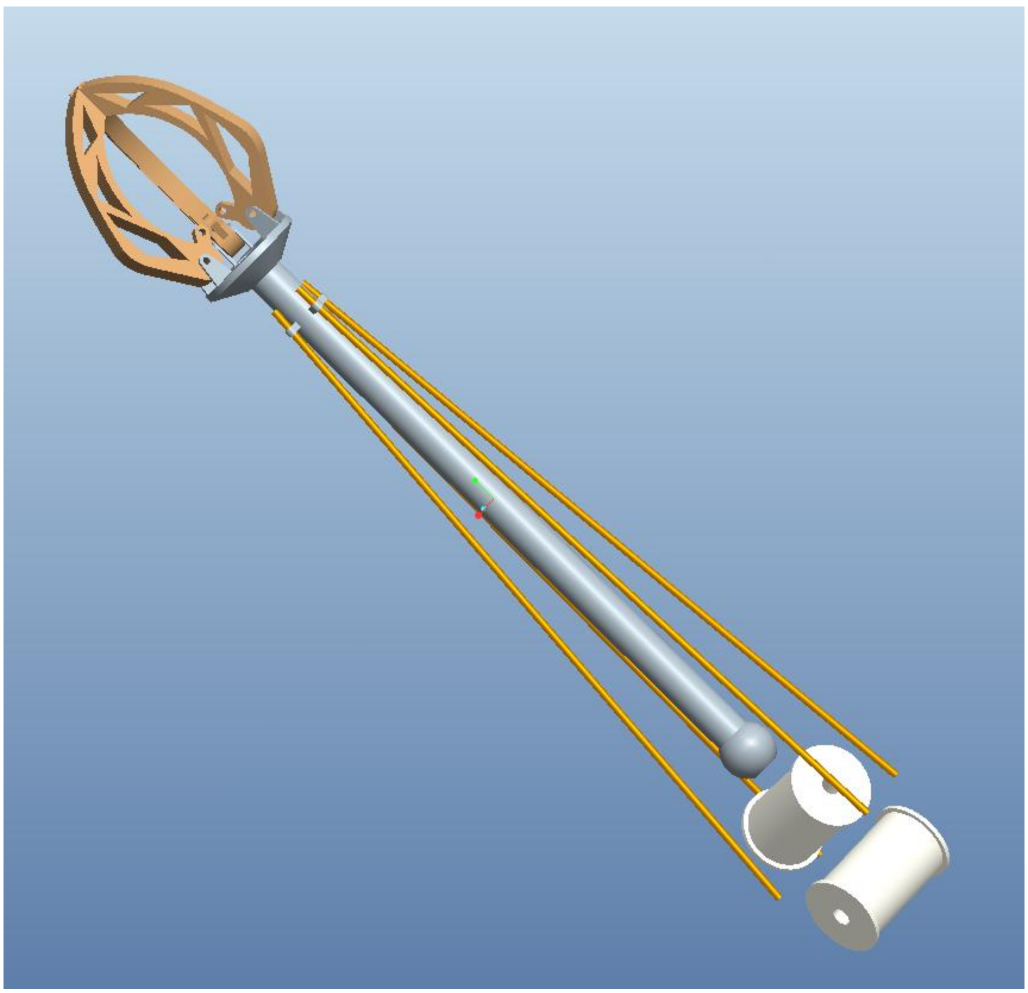


Design C

This is the final working design chosen by Team Azul. Known as design "C," it is believed that this frame will offer the best compromise between a low drag coefficient, versatile open-frame design, maneuverability, cost, and weight. The frame is designed so that it may be constructed in its entirely from one 3' by 2' sheet of plastic, and the supporting members cut out from the larger sections, saving on material. These sections will then be bolted, riveted, or otherwise fastened together.

Robotic Arm

The requirement was established for a 3-axis robotic arm, and several methods were considered to solve this problem. Ultimately, traditional solutions involving servo motors at each joint were eschewed in favor of the following design, developed by undergraduate assistant Jessica Fletcher. This design works by the actuation of several sets of steel cables in a "tendon"-configuration. This arm will most likely be machined out of aluminum; this, coupled with the high breaking strength of the cables, will mean the primary determination of strength in this part of the ROV will be the three servo motors used to drive the arm. These motors will be mounted within the ROV, near the base of the arm (not shown).



As can be seen in the previous illustration, the steel cables attached to hardpoints outside of the arm are wrapped around spools which are then rotated to move the arm across the x-z or y-z planes. The center of the arm shaft is hollow to allow three additional cables to actuate the gripper fingers, which are held open by a set of springs.

During the course of the semester, the idea to build a manipulator was dropped due to funding issues and other constraints. Also, the MATE competition requirements do not require one, so the plan was not pursued as actively as control systems or propulsion –key components of the ROV. Plans are in place to utilize non-moveable tools such as a saw and clip to meet MATE requirements and plans of building a manipulator are put on hold till funding and interest can be found.

Material Density and Thrust-to-Weight Ratio

Given the preliminary data, a full complement of SeabotixBTD150 thrusters will be used – this will provide vectored thrust along the x-y plane. The following table calculates the thrust vectors, which are at 45-degree angles to the thrusters as mounted on the chosen frame design.

This table (Pls. see Table 2) shows the calculations of the thrust-to-weight ratios of the last two iterations of Team Azul's designs. Designs "B" and "C" were initially designed with a total footprint of 3' by 2' by 1.5' to fulfill competition requirements while remaining in the same size class as competing general-purpose ROVs. However, the subsequent mass of the appropriately-sized frame was too much for the Seabotix thrusters to handle effectively. Afterwards, both the "B" and "C" designs were scaled down to 75% of their original size. The data below will reveal the evolution to an adequate design.

Of the two plastics contemplated, High-Density Polyethelene (or HDPE) was chosen over ABS plastic simply because of its slightly superior performance. If there are any problems encountered with HDPE, ABS provides a ready alternative due to its similar characteristics.

Material Properties Design A							
Material	Yield Strength(Mpa)	Tensile Strength(Mpa)	Density(Kg/m^3)	Volume of Frame(m^3)	mass of Frame(kg)	density of water(kg/m^3)	Weight of Frame in Water(N)
Al 2014	97		2800	0.017156	48.04	1027	298.40
HDPE	**22.06**	**31.37**	**950**	**0.017156**	**16.30**	**1027**	**-12.96**
ABS		**29.64**	**1024**	**0.017156**	**17.57**	**1027**	**-0.50**
PTFE	23	25	2158	0.017156	37.02	1027	190.35
Scaled Down Frame							
Al 2014	97		2800	0.0072	20.16	1027	125.23
HDPE	**22.06**	**31.37**	**950**	**0.0072**	**6.84**	**1027**	**-5.44**
ABS		**29.64**	**1024**	**0.0072**	**7.37**	**1027**	**-0.21**
PTFE	23	25	2158	0.0072	15.54	1027	79.88

Material Properties Design B							
Material	Yield Strength(Mpa)	Tensile Strength(Mpa)	Density(Kg/m^3)	Volume of Frame(m^3)	mass of Frame(kg)	density of water(kg/m^3)	Weight of Frame in Water(N)
Al 2014	97		2800	0.0068	19.04	1027	118.27
HDPE	**22.06**	**31.37**	**950**	0.0068	**6.46**	**1027**	**-5.14**
ABS		**29.64**	**1024**	0.0068	**6.96**	**1027**	**-0.20**
PTFE	23	25	2158	0.0068	14.67	1027	75.45
Scaled Down Frame(75% of Original Size)							
Al 2014	97		2800	0.0028	7.84	1027	48.70
HDPE	**22.06**	**31.37**	**950**	0.0028	**2.66**	**1027**	**-2.12**
ABS		**29.64**	**1024**	0.0028	**2.87**	**1027**	**-0.08**
PTFE	23	25	2158	0.0028	6.04	1027	31.07

Thrust to Weight Ratio Design A

Material	mass of ROV (kg)	mass of components (kg)	total mass (kg)	Weight	Thrust to weight
Al 2014	750.4	3.56	753.96	7396.35	0.01
HDPE	**256.6**	**3.56**	**260.16**	**2552.17**	**0.02**
ABS	**274.43**	**3.56**	**277.99**	**2727.08**	**0.02**
PTFE	578.34	3.56	581.90	5708.44	0.01
Scaled down Frame(75% of original size)					
Al 2014	317.52	3.56	321.08	3149.79	0.02
HDPE	**107.73**	**3.56**	**111.29**	**1091.75**	**0.06**
ABS	**116.12**	**3.56**	**119.68**	**1174.06**	**0.05**
PTFE	244.72	3.56	248.28	2435.63	0.03

Thrust to Weight Ratio Design B

Material	mass of ROV (kg)	mass of components (kg)	total mass (kg)	Weight	Thrust to weight
Al 2014	19.04	3.56	22.60	221.71	0.28
HDPE	6.46	**3.56**	**10.02**	**98.30**	**0.63**
ABS	6.96	**3.56**	**10.52**	**103.20**	**0.60**
PTFE	14.67	3.56	18.23	178.84	0.35
Scaled down Frame(75% of original size)					
Al 2014	7.84	3.56	11.40	111.83	0.55
HDPE	2.66	**3.56**	**6.22**	**61.02**	**1.01**
ABS	2.87	**3.56**	**6.43**	**63.08**	**0.98**
PTFE	6.04	3.56	9.60	94.18	0.66

ProE Calculations

After frame "C" was chosen, analyses were run in ProEngineer software to simulate a 20 lb load upon the top bar of the frame, leaving the bottom constrained, to test the basic structural stability of the frame. These results are shown below, are summarized by the result that total stress on the frame did not exceed 303 psi, well within the yield stress limits for HDPE(Maro Polymer). Also included are graphs of stress, displacement, and strain along the outer edge of the ROV frame. Please see Figure 2.

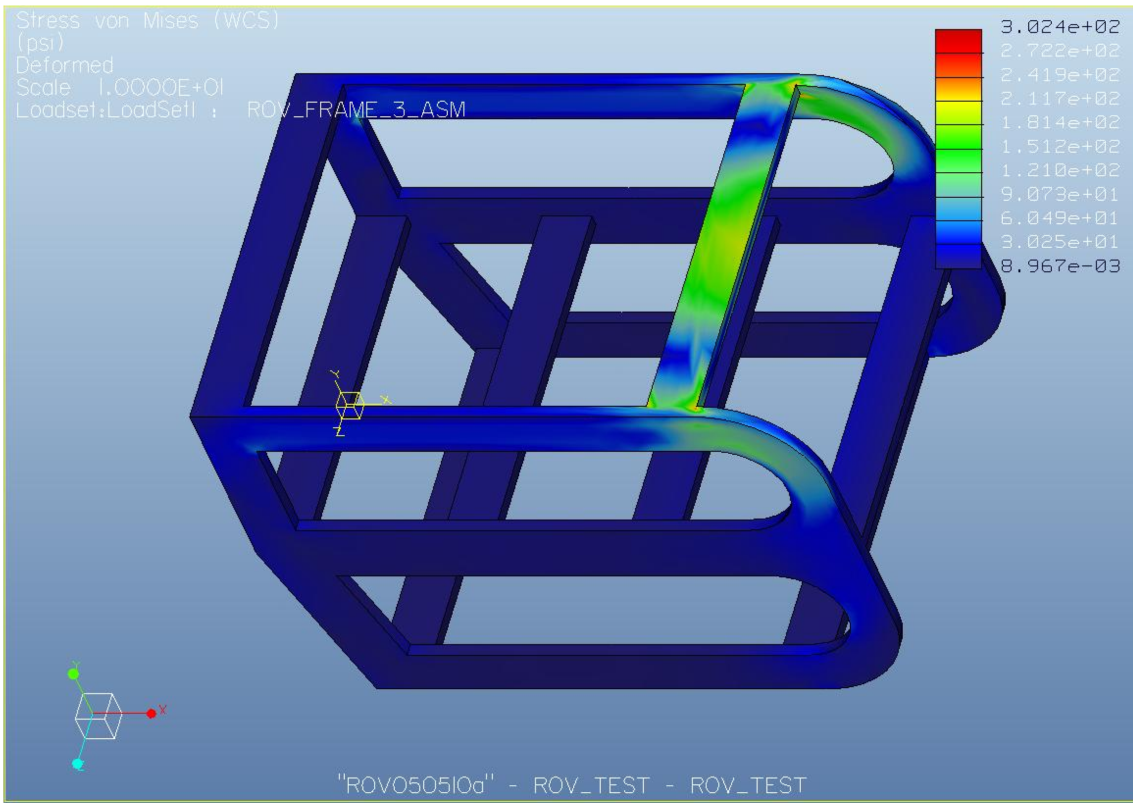


Fig. 2

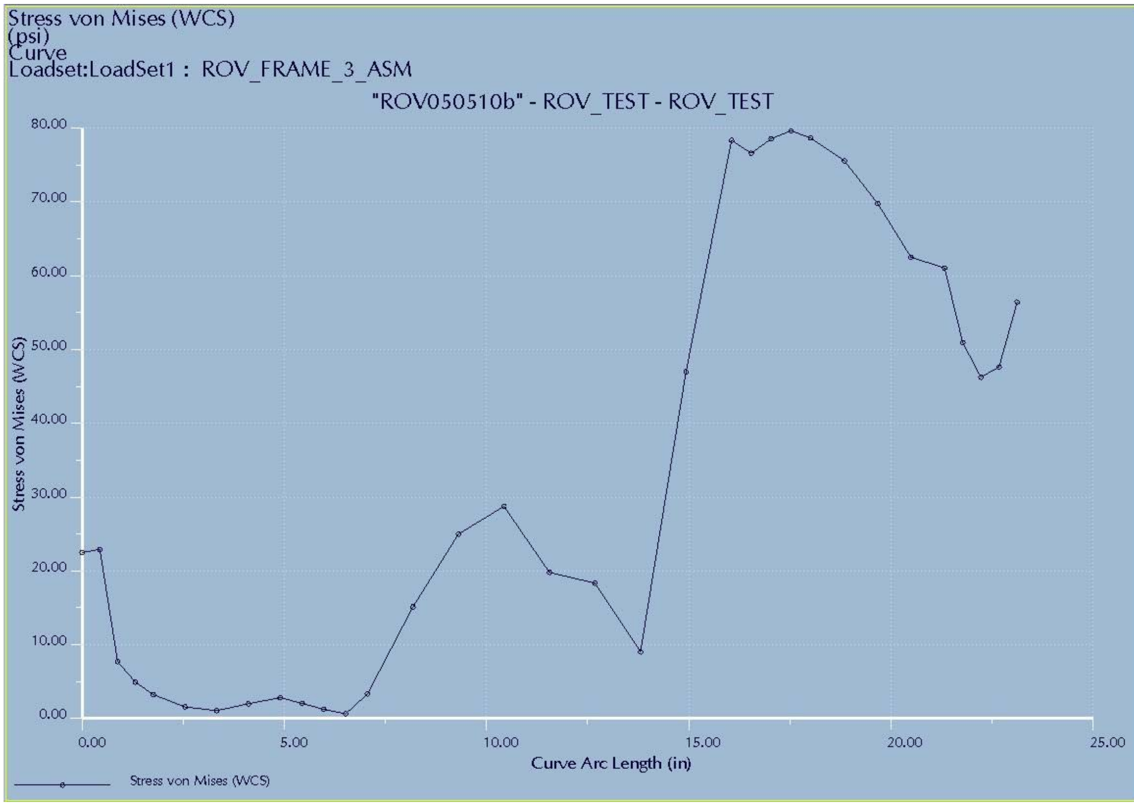
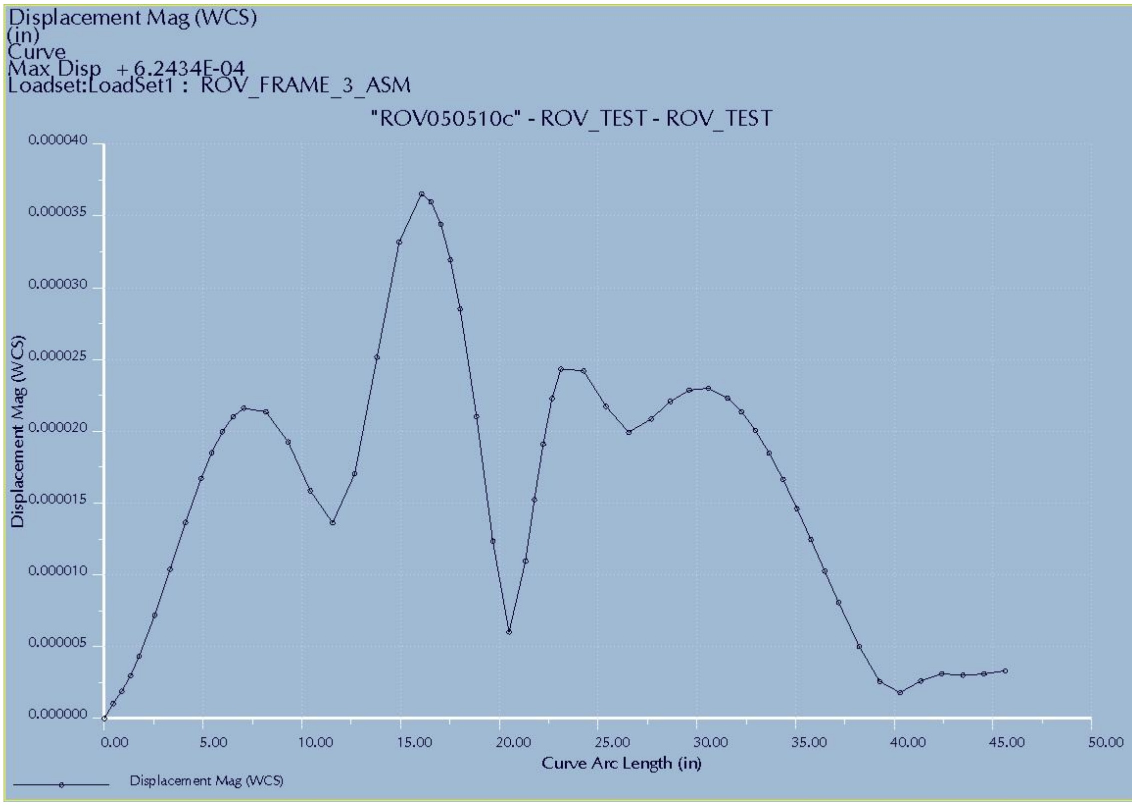


Fig 3

Fig 3: (Above) Von Mises Stresses are tolerable by our choice of HDPE frame material. Along the 'path of curve' of our testing, all VMS stayed within predicted range. Safety margin of 2 was calculated within the testing parameters.

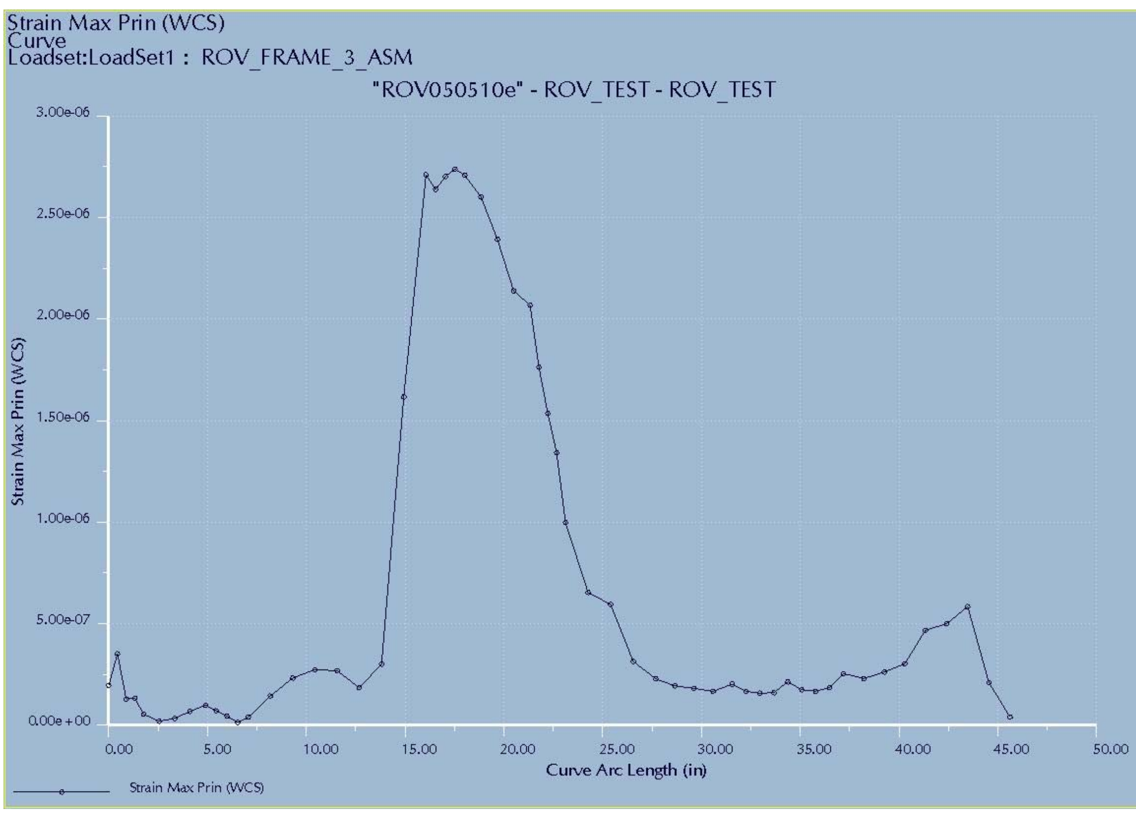
Fig 4: (Below) Displacement amounts are within range with the HDPE frame material. Safety margin of 2 was calculated within the testing parameters and the material movement was still not noticeable.

Fig 5: (Below) Strain numbers are within range with the HDPE frame material. Safety margin of 2 was calculated within the testing parameters and the material has allowance for much greater strain capacity.



Displacement Mag (WCS)
(in)
Curve
Max Disp +6.2434E-04
Loadset:LoadSet1 : ROV_FRAME_3_ASM
"ROV050510c" - ROV_TEST - ROV_TEST
Displacement Mag (WCS)
Curve Arc Length (in)
Displacement Mag (WCS)

Fig4



Strain Max Prin (WCS)
Curve
Loadset:LoadSet1 : ROV_FRAME_3_ASM
"ROV050510e" - ROV_TEST - ROV_TEST
Strain Max Prin (WCS)
Curve Arc Length (in)
Strain Max Prin (WCS)

Fig5

Thermal Calculations

Thermal calculations were conducted to see how much heat would have to be dissipated from the H-bridges and microprocessor, from within the electronic control boxes, before the temperature became disruptive. A minimum of $0.02m^2$ was required to dissipate the heat generated from within in the control boxes to keep the CPU and H-bridges running. Please See Diagram 1 below.

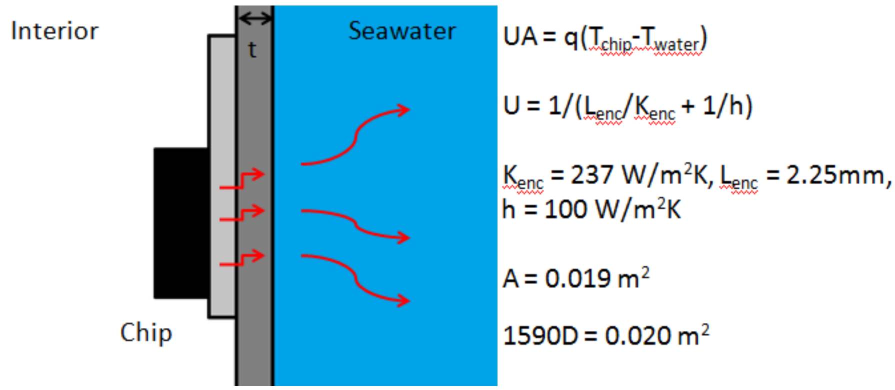
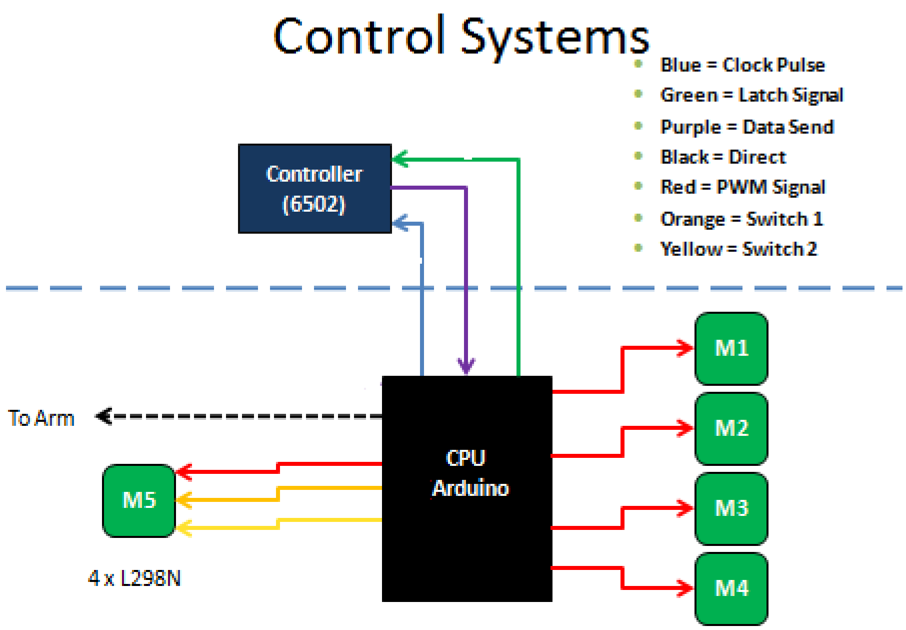


Diagram 1

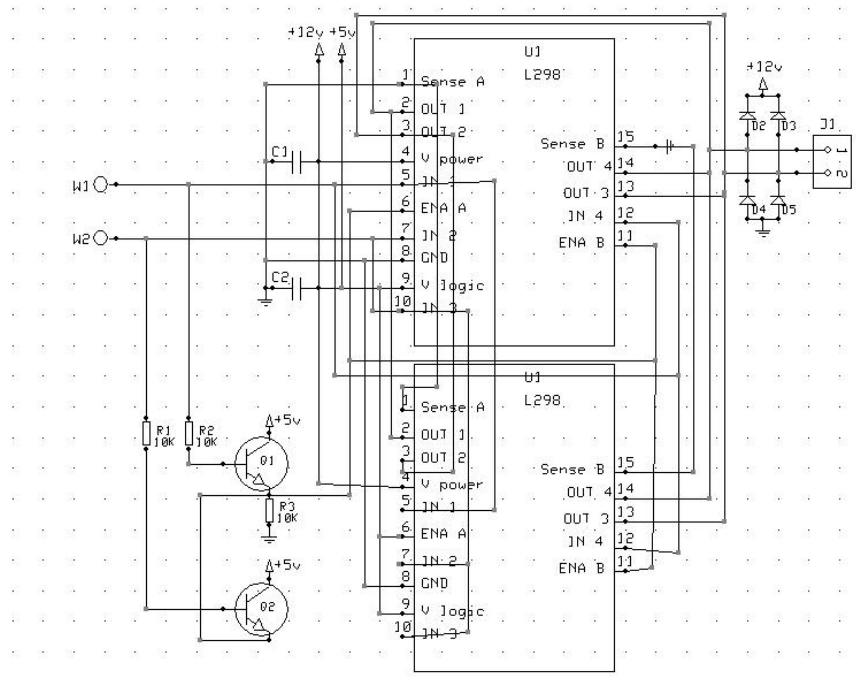
Control System

The control system in use is defined by the diagram below. The ROV will be controlled with a SNES powered controller interfaced with anArduino CPU. The SNES running on the surface (topside) connected to the bottomside with the CPU will be twisted pair serial cables which run through the tether, sending control signals through the CPU to the individual motor H-bridge controls and Omron relay. The CPU will also handle signals from simple sensors such as the metal detector; more complex imaging devices, such as the sonar system, will be routed separately through a higher-resolution interface directly to the surface. The H-bridges in question will be 4 parallel pairs of L298N devicesused to operate at higher frequency and more precise to be multi-directional. The Omron relay G5RL1A to control the onboard motors is a single direction SPST –single pole single through relay. (Pls. see Fig. Zuchlewski)

Note: Please See Appendix ‘Operating Manuel’ for details on circuit configuration and calculations.



CPU will use Ethernet for control and communication. This inexpensive and versatile cable can be wrong long distance, but offers dependability, with little signal loss, in short runs. An embedded web server can allow for real time data acquisition. This data is mainly for the video feedback and other tools the team is to place on the ROV. Data from the server can be streamed real time to a website including video, sensor, and coordinates. This is important so the driver can make real time decisions on direction and things of interest. The five motors will be controlled by the SNES controller by the Arduino CPU, which controls the pathways. The control signals and the ampageis given by the CPU, which will be used to control the forward and reverse movement. If the control signal from the CPU is 01 then Motor1 will be activated. And accordingly if a control signal 11 is sent from the CPU then Motor2 is activated.



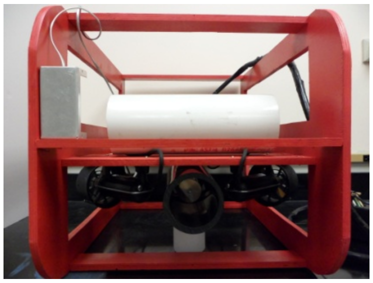
The two H bridges can only handle 4 amps each. Two 4 amps circuit creates an 8 amps parallel circuit. The first is 5 V and the second is 20 V. The Logic Power eliminates the noise within the system, this is done so the circuit is not disturb and automatically breaks due to vibrations. Using Pulse Width Modulation (PWM), an Average voltage can be simulated to the H-bridges. The CPU will output PWM to the H-bridge circuit to control motor speed. Temperature sensors are placed next to the motor and in the water to limit the efficiency of the motor. This is done to prevent a blowout of the motor and circuits.

CMOS 4201 controller transmits and receives data serially to and from the CPU. The CPU sends a latch when ready for RX, the first bit is TX via data out. CPU sends 15 clocks pulses for the remaining 15 bit, which is computes data in microseconds. The CPU outputs commands to H-bridge.**Please See Appendix 'Operating Manuel' for details on circuit configuration and calculations.**

Build & Testing

Attempt I:

The first prototype was constructed October 8 out of a wooden frame by Team member Walter and electronic control boxes were constructed to control the 3 donated Seabotix motors. (*Pls. see Picture 7*) Sealing the electronic boxes was of vital concern, which was not properly done. The electronic boxes were sealed using silicon and were breached by the water damaging wiring and H-bridges. This could have not have been anticipated, due to the veracity with which technical advice was given by a known ROV builder. One fault may have been the unusually large amount of silicon used to seal cable inlets into the electronic boxes of which the interior of may have never dried and sealed properly. Another was the inflexibility of the silicone, when attached between metal boxes and flexible cables, the silicone always seemed to 'give' a little, allowing for possible water leaks. In the process of opening and resealing these electronic boxes, a few of the screws were stripped and new boxes had to be purchased. Salvaging the old boxes was initiated, but the screws were so worn out by the end that new ones were necessary to precede further.

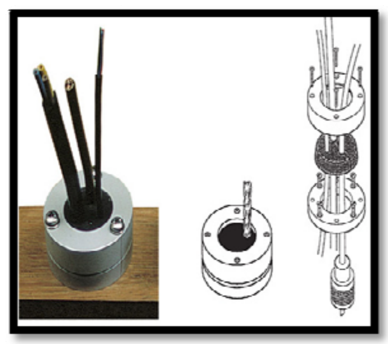


Picture 7

Attempt II:

By November 17 the team realized that water breach of the electronic boxes was a major obstacle to overcome and this must be achieved for survival of the ROV program. Immediately BLUE SEA SYSTEMS 'CableClam Waterproof Through-Deck Fittings' fittings were ordered for $173 to tackle the leak issue (Pls. see Picture 8 & 9). These connectors were ordered for overnight delivery and came with excellent reviews by the ROV building community. Each separate cable that was going into the electronic boxes was given a watertight seal 'CableClam' and additional one for the tether one. These 'CableClam' connectors work by drilling into the electronic boxes to attach a watertight foundation. Once this is in place, a rubber cork is drilled just enough for passing the cable through and another fitting seal screwed into the foundation fitting to keep everything in place. This system worked perfectly under ‘sink’ tests, but failed when once again the metal electronic boxes were breached through the stripped screws in the new boxes. Also the box tops were assumed to be watertight, as mentioned by the manufacturer, but water leaked quickly through the tops. All systems would fail and would have to be rewired with new H-bridges once the water breached the electrical boxes. Our $102 SM5100B cell phone controller chip (cellular shield), a device that would allow control of our ROV through cell phones, was ruined by such a water breach. Our prototype was made from wood and we over-waited for our HDPE material to arrive –requiring multiple phone calls with the vendor for timely delivery. At this time we had to change our initial circuit unit from a multiplexor to an Arduino because the multiplexor was not handling the load and processing quickly enough. Wiring the ROV was a huge challenge due to the lack of electrical experience mechanical engineers have.

Picture 8



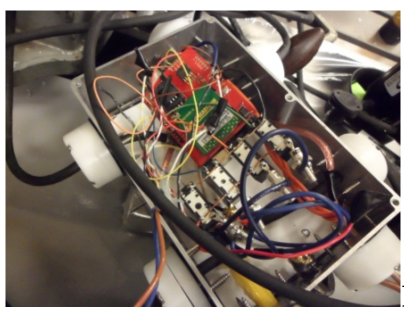
Picture 9

Attempt III: Final Build

By November 30, 2010 the HDPE frame was cut and built and new electrical boxes without any stripped screws capping the top were attached to the frame. (Pls. see Picture 10, 11, 12) ‘CableClam’ connectors were used to attach all cables and tether line and the ROV was tested in pool conditions at a depth of 8 feet. Video Cameras were attached in the front and back of the ROV per MATE competition requirements and the video line was run up the tether line. The team was prepared with previous water leaks and this time used new electrical boxes with new screws. Just to be cautious, the caps were sealed with a thin layer of silicone gel. The HDPE frame was sturdy and light and offered easy drilling for the modular design –parts could be attached and removed with ease. ‘CableClam’ connectors were verified for sealing ability along with the tops.

The test was a success with all the recent changes. Electrical boxes did not leak water damaging the H-bridges or Arduino processor. The ‘CableClam’ connectors held up along with the box tops to prevent water from breaching in. The sturdy HDPE frame was able to gently float around the pool and was very maneuverable. One issue was the control of the buoyancy and this was attributed to not calculating for fresh water pools adequately. Another reason may have been not getting the exact material we had ordered and its density not being reported. For future changes we would have to recommend a buoyancy control device be added to the ROV and not completely be dependent on vertical thrust motors; however, the test and the final build was a success.


Picture 10


Picture 11


Picture 12

Conclusion

In conclusion, Team Azulhas constructed a viable ROV for commercial and competitive use. Further considerations include more ProEngineer stress calculations to optimize the frame design, as well as computational fluid dynamics analysis to study the ROV's in-water characteristics. Also, the behavior of all considered materials in saltwater must also be studied, to avoid corrosion and stress cracking issues. With all that has been taken into consideration the ROV is now famously referred to the B.O.S.S. The Buoyant Open-Architectural Submersible System (B.O.S.S.) is the ROV that will be used in the 2011 MATE competition.

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Table 6:2	Super NES Controller Port Pinouts	
Pin #	Function	Wire Color
1	+ 5 power	White
2	Clock	Yellow
3	Latch	Orange
4	Data Out	Red
5	No Connect	None
6	No Connect	None
7	Ground	Brown

Operation	Latch	CLK	CLK	CLK	CLK	CLK	CLK	CLK	CLK	CLK	CLK	CLK	CLK	CLK	CLK	CLK
	bit 0	bit 1	bit 2	bit 3	bit 4	bit 5	bit 6	bit 7	bit 8	bit 9	bit 10	bit 11	bit 12	bit 13	bit 14	bit 15
Data	B	Y	Select	Start	Up	Down	Left	Right	A	X	L	R	1	1	1	1

SNES Data Format — Figure 6:7