M.A.R.O.V Team

Engineering Technical Report

"Hallie"

Submitted by: **Milton Academy R.O.V. Team**

Milton, MA.

June 1, 2006

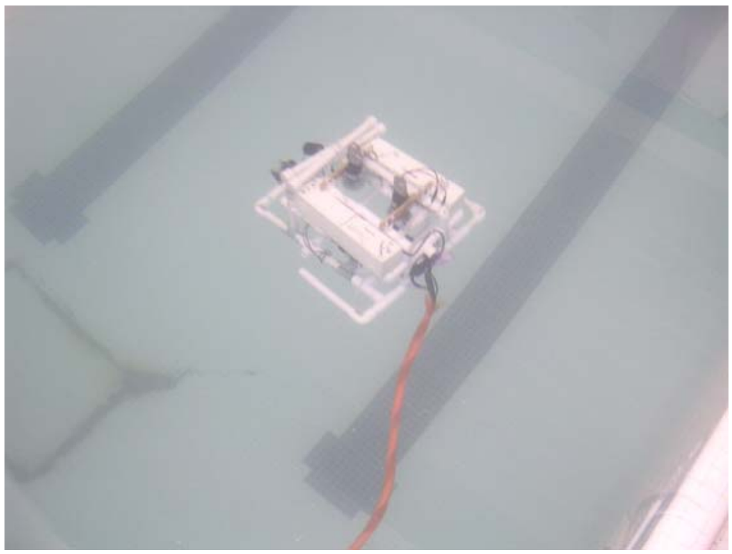

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Table of Contents

Abstract…………………………………………………………… Page 3

Design Rationale………………………………………………… Page 3

Thrusters…………………………………………………….. Page 4
Gripper Use and Camera Placement……………………. Page 6

Budget and Expenses Sheet………………………………………. Page 8

Electrical Schematic……………………………………………….. Page 9

Description of a Technical Feature of the R.O.V. Industry… Page 10

Description of Organizations that Employ ROVs…………….. Page 11

Challenges and Trouble Shooting……………………………… Page 13

Future Improvements…………………………………………… Page 15

Lessons Learned………………………………………………….. Page 17

Acknowledgements……………………………………………… Page 19

ABSTRACT

This technical report encompasses the designs and construction of "*Hallie*", designed, built, and operated by Milton Academy's Remotely Operated Vehicle (M.A.R.O.V.) Team for M.A.T.E.'s 2006 New England Regional and International Competitions. *Hallie*, our response to the 2006 Ranger Mission Tasks, began approximately two years ago as the brainchild of a dozen Milton Academy students, united in their collective passion to design, build, and pilot R.O.Vs. Together, they built *Henrietta*, a design that we have used to inspire us in our quest to compete in this year's M.A.T.E. competitions.

Hallie, which translates as: "thinking of the sea" in Ancient Greek, is hardly a stranger to adversity. From our earliest glimmer of a blue print to our finished product, *Hallie* has been designed and constructed as *Henrietta's* more advanced offspring to counter any challenges she meets while completing her two underwater missions in '06.

This report includes notes summarizing our design rationale, challenges we have encountered, troubleshooting ideas, the lessons we have taken away with us, ideas for future improvement, and organizations that employ ROVs.

Hallie is the result of many hours of collaborative, productive, determined, and disciplined work by a group of high school students focused on an idea and trying to fulfill the mission tasks of M.A.T.E.'s 2006 Ranger Class competition.

DESIGN RATIONALE

Our submarine was based on the principles of K.I.S.S. (Keep It Simple, Stupid!), and in keeping with our mantra, we focused on maintaining her maneuverability, technical efficiency, reliability, and speed.

Frame:

For the body of the sub, we designed a workhorse, rectangular frame. We made that decision because, while not as hydrodynamic as the sphere, the box "sled" shape is sturdy, provides an even distribution of weight, and allows for ample room for storage and equipment. We built our 'bot' with over 40 pieces of schedule 40 PVC piping and joints, including clear PVC (potentially for camera view), wooden support structures for thruster mounts, and nylon mesh and cable ties for support and structural integrity.

Approximate out-of-water mass = **3.9 kg –** Hallie alone mass
(Weight = **38.2 Newtons**)
With tether and control box = **8.7 kg –** total mass
(Weight = **85.3 Newtons**)
Approximate Volume of Hallie = $\mathbf{2.4 \times 10^{-3}\ m^3}$
Volume of Water Displaced ~ **2.4 Liters**

The sub was also designed with the thrust and turning efficiency of the engines in mind, creating an obstruction-less pathway for vertical and horizontal water flow. Because the submarine is a flow-through, "wet sub", we did not feel the need to make the sub hydrodynamic, yet more workman-like, stable, and practical. The ***BG*** is maximized for stability.

During the first task, *Hallie* will be outfitted with a passive, buoyancy compensator, approximately 0.5 liters in volume to support *Hallie* as she transports the module to the frame at depth. When the module, at approximately **0.5 kg** mass when submerged, is set in place in the frame, *Hallie's* pitch will be adjusted using the vertical thrusters and the buoy will be free to float to the surface. *Hallie's* drivers will in turn be able to now operate her for the remaining tasks of the first mission.

Preliminary Configuration with Test Sled, February, 2006 M.A. Lab Area

Motors:

Hallie has four thrusters: two vertical and two horizontal. The horizontal motors control the x- and z-plane movement (forward, backwards, clockwise- counterclockwise turning) and are mounted on the outer middle edges of the submarine in close approximation to the center of mass so as to both facilitate movement and reduce the turning radius.

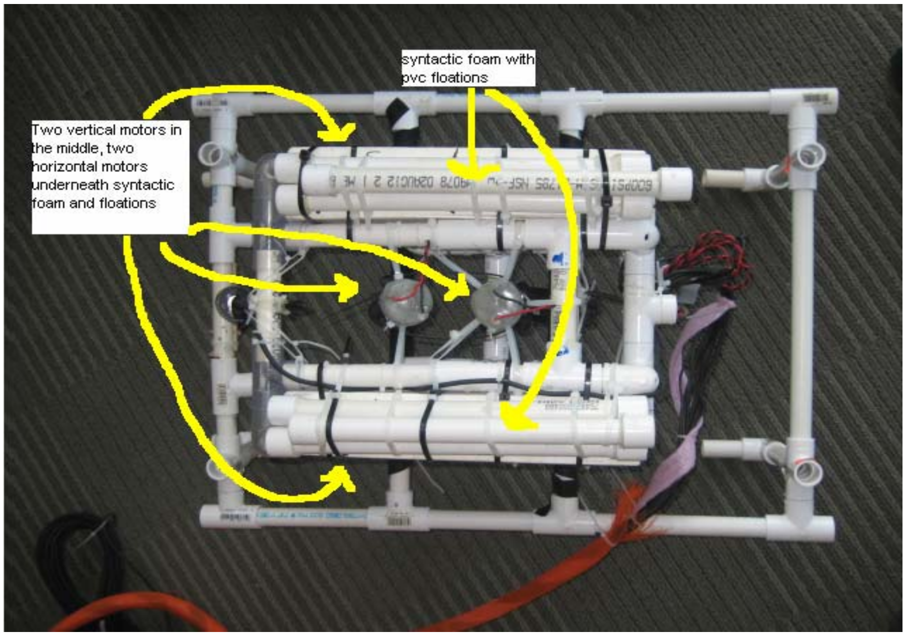
We mounted the vertical motors on the top of the submarine, with the propellers slightly higher than the center of buoyancy, so that *Hallie* remains upright and stable during its descent and ascent. Because we placed all of the flotation in the upper half of the sub, the center of buoyancy is higher than the center of gravity, and therefore the submarine is stable during its descent (BG is lenghtened). All of the motors have a clear path to facilitate water flow particular when *Hallie* is first lowered into the water and commences descent..

The motors are mounted so that the submarine gains more power for advancing forwards and rising upwards while thrusters are mounted in such a way that shrouds are not needed as we have protected the propellers from any type of interference with obstacles or pool missions.

Sealed, Heat Shrink Tubing Johnson Motors, April, 2006

When under load the 4 thrusters are averaging a current draw of almost 16 amperes in water with 12 V-DC across the circuit. In addition to the minimal draw of the cameras (~150 mA/camera) and 4.7-6 V-DC Lynxmotion servo-poweredgripper (< 1 A), the maximum amperage limit will be well under the 25-amperes allowed. The main power is protected within the control box, with a 25-amp slow-blow fuse.

Four pairs of 18-AWG wire conduct the power through the tether to *Hallie*. The tether is actually made up of Belden hypalon lead 18-AWG wire that has been spliced to the standard 18-AWG hook-up red/black wire for better flexibility and subsequent control of our vehicle. The 18-AWG provided a tolerable voltage drop along 10 meters of wire and carried the current we needed.



Preliminary Hallie Configuration, February, 2006

After several thruster trials, we decided to fit our submarine with 12 VDC Johnson workhorse motors (7800 RPM), later matching them with Graupner 3-blade and 4-blade propellers (50-mm & 60-mm respectively) for the horizontal/vertical thrusters; this allowed efficient current use and optimal thrust through the less-viscous, chlorinated medium. We found these propellers to give us more thrust than Dumas (2-blade #3003) or other brands we tried. We knew we needed low pitch, large surface area, non-metal propellers, and these blades gave us slightly more thrust and appeared to match well with the motors.

We were consistent in our placement of the propellers on the shaft to allow for adequate movement of water to flow across the blades. We used a couple of methods to maintain similar distance between blade and motor, including washers, cardboard and foam to measure and protect the sensitive motor housing from epoxies.

The Johnson motors were high performing in our ‘Bollard Pull’ tests as compared with sealed bilge pump motors, and certainly more cost effective for our many trials and overhauls of our vehicle.

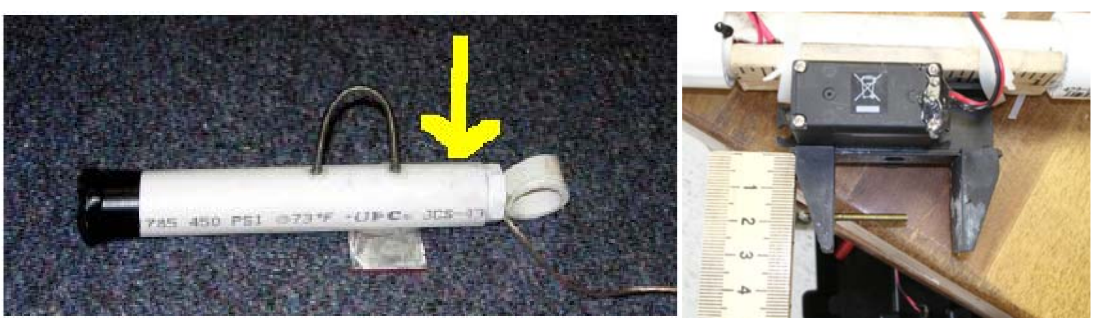
‘Bollard Pull’ tests revealed our motors to be operating at 4-5 amperes when under load and resulted in close to **6-8 Newtons** of thrust with the Graupner 3-blade , and 4-blade propellers of this 50-mm and 60-mm diameter. The 4-blade propellers gave us a little more torque and slightly more current draw than the 3-blad propellers at top speed, and thus we chose to use these with our vertical-oriented thrusters.

We have waterproofed our motors with heat shrink tubing of 2” diameter (McMaster-Carr) and sufficient amounts of marine GOOP, marine silicone sealant, and hot glue. While we recognize that this approach is not possible in a real-world situation, in which the submarine is exposed to more harsh conditions and also to a salt-water environment, we nevertheless recognized that the overall increase in rpm performance with our Johnson motors is far superior when compared to bilge pump motors. For that reason, and for the sheer cost associated with purchasing larger, less powerful motors, we selected and used the 12 VDC Johnson motors.

Gripper Use and Camera Placement:

Ultimately, M.A.R.O.V. decided to use a Lynxmotion gripper—to retrieve the power/communications cable connector.

The gripper, in its newest postion, would face toward the bottom of the pool and would be visible from the forward camera. We would grab the cable connector in the area indicated in this photo, using the U-bolt’s position to help guide our pilot.



Power/Communications Cable Connector Mock-Up/ Gripper with Lock Pin, March, 2006

The Lynxmotion gripper, originally used with a servo motor; was modified to use as a simple DC motor because, for our purposes, all we needed was a simple on/off switch. The gripper is located towards the front of the submarine and can be seen by both cameras.

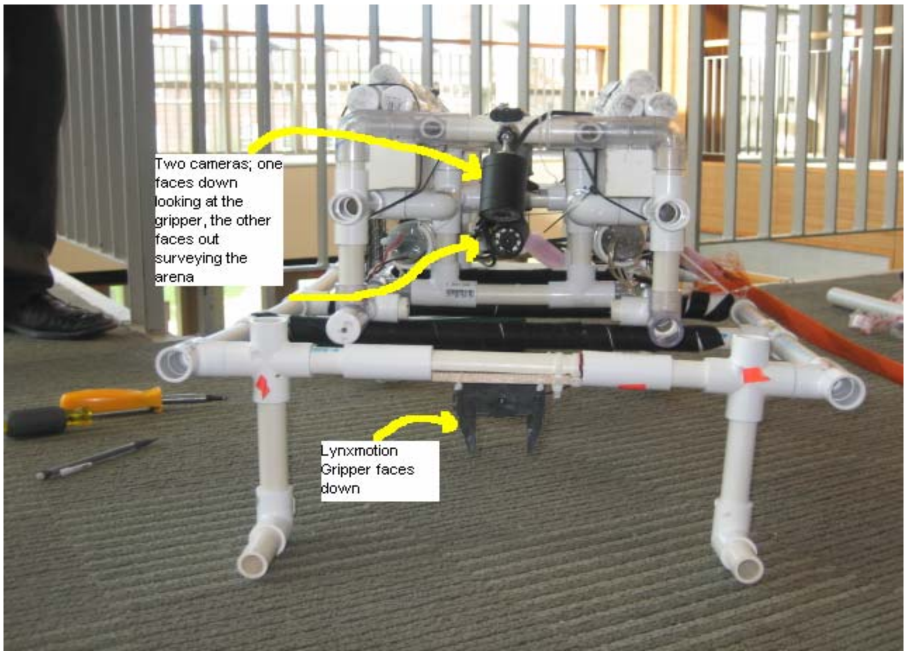
The gripper is being powered by a 12V-to-6V DC converter, purchased for under $20, that we opened, mounted to a heat sink, and connected to our control box. The

Lynxmotion gripper works on 4.8-6 VDC and worked efficiently and reliably with this innovation in our design.

Cameras

Two of the cameras are B&W CWC waterproof cameras that are sealed so as to prevent the corrosive effects of water. Around the front lens of the camera is a ring of 8 LEDs that provides low-power infrared (IR) light. The cameras are placed on the top and on the rear of the submarine. The rear camera faces forwards, through the sub and would be used for general navigation and for both mission tasks.

At press time, a third color LCA 7700 camera was being considered for use on *Hallie*, to view behind the vehicle and add another dimension of recognition as we navigate the underwater environment during the competition.



Preliminary Configuration with Test Sled, Milton Academy Lab, March, 2006

Tether:

We used an orange sleeve to organize the wires into a single tether and to prevent wires from interfering with the propellers. Within the sleeve, we ran 8 lines of 18-AWG wire wrapped with internal polystyrene foam (for the first 6 meters) to create buoyancy and to avoid twisting the wires.

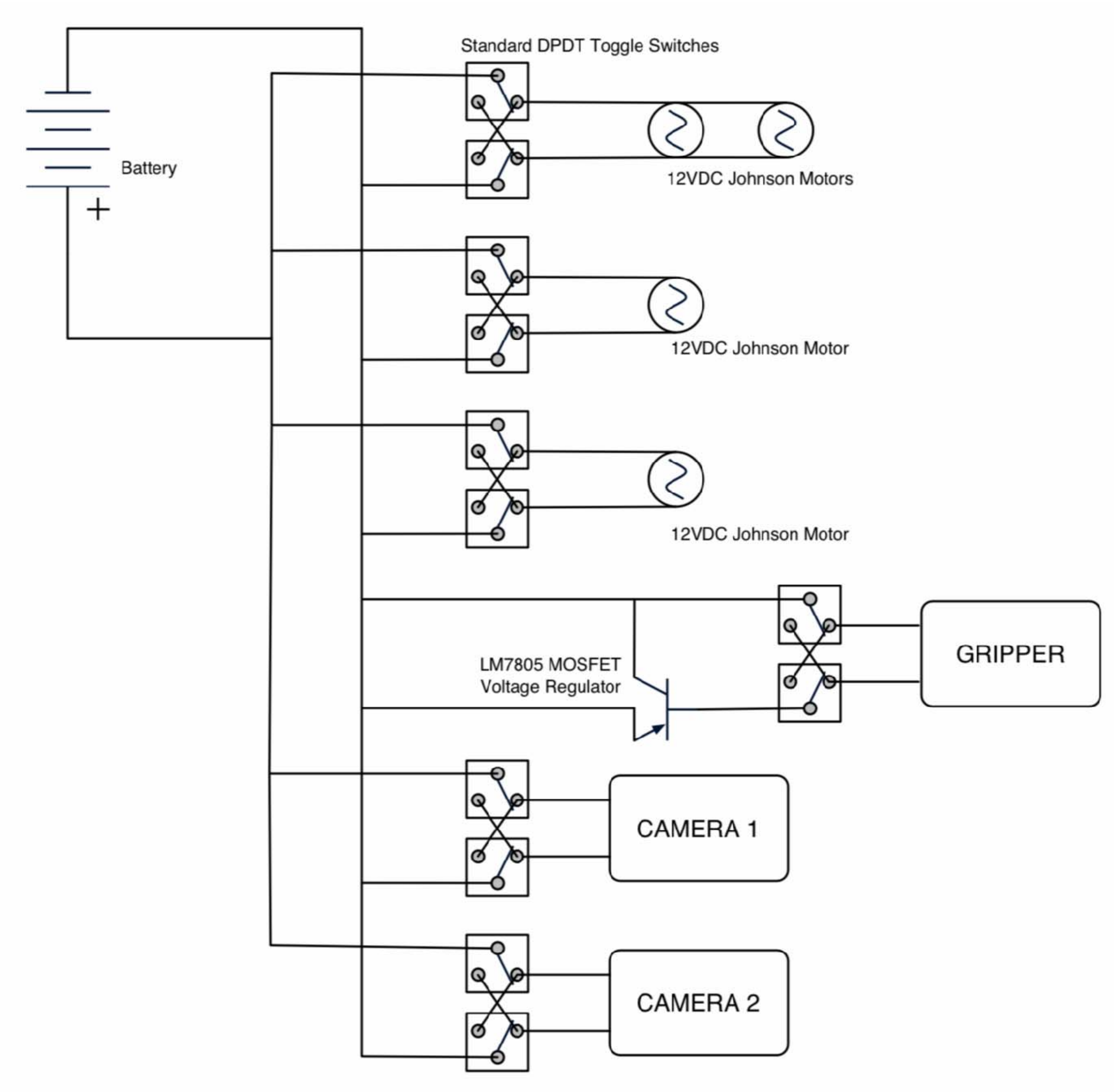
Budget and Expenses

Materials Description	*Qty.*	*Unit Price ($)*	*Cost($)*
B&W Pro-View CVC 321 WCP Camera	2	99.00	198.00
12VDC Johnson Motor	12	2.95	35.40
Standard Servo HS-422 S2-01	2	12.99	25.98
Little Grip Kit, LG-KT, Lynxmotion	1	40.98	40.98
Graupner Propellers 50-mm R, 3-blade	4	4.10	8.40
Graupner Propellers 50-mm L, 3-blade	4	4.10	8.40
Graupner Propellers 60-mm, R, 4-blade	2	4.95	9.90
Heat Shrink Tubing, 7132K81	2	7.76	15.52
Stranded Single-Cond. Wire, 18-AWG, B	300’	9.89/100ft.	29.67
Stranded Single-Cond. Wire, 18-AWG, R	300’	9.89/100ft.	29.67
25-A Slow-Blow Fuses	2 pkg.	5.95	11.90
Stranded 14-AWG Wire	1	9.95	9.95
Jameco Switches, Rocker, Toggle	6	4.00	24.00
Nylon Cable Ties	2	8.75	17.50
Plexiglass Mock-Up, Freeman & Co.			41.00
6”x 4”x 2” Project Box	2	4.99	9.98
Vanco Fuse Holder	2	3.75	7.50
Fuse Holders	2	6.00	12.00
In-Line Fuse Holder	2	4.00	8.00
Schedule 40 PVC & clear PVC			25.00
Tether Sleeve	1	30.00	30.00
12V-6V DC Converter	1	19.90	19.90
Heavy Duty DPDT Switches- Radio Shack	4	3.99	15.96
Stranded 16-AWG Wire	1	7.75	7.75
U-Bolts Mock-Up	6	2.50	15.00
Aluminum Bracket Mock-Up	2	4.50	9.00
Belden 34918 Hypalon Lead Wire 18-AWG	2	65.00	130.00
Color Camera LCA-7700	1	195.00	195.00
Pipe Insulation	2	1.90	3.80
PVC Cutter	1	10.95	10.95
Tool Boxes	2	12.00	24.00
Sterilite & Rubbermaid Totes	3		36.00
Powerpole Connectors, 35-A			25.00
Duct Sealant	1	5.00	5.00
Silicone Sealant	2	8.00	16.00
Marine Deep Cycle Battery	1	95.00	95.00
Total			***~ -1,207.00***

Contributions & Donations

N.E. Regional 2nd-Place Award	$500
M.A. Pizza Fund Raising Sales	$400
Science Department Aid & Headmaster's Award	$450
Total	*+$1,350*

Electrical Schematic



Buoyancy:

We recently found some problems with the copper pipe, foam insulation that we have been using in that the insulation compressed under the strain of the pressure caused by depth. Ultimately, we decided to use syntactic foam (See next section for discussion about syntactic foam). Although, when we received a sample of the foam, it was quite hard and heavy, and we found that due to the fact it is difficult to cut and form with a handsaw made in 1922, we were only able to use two large chunks of it on either side of the sub. Since we keep our sub neutrally buoyant and balanced, it is easier to divert foam in smaller sections to other parts of the sub to balance the buoyancy.

Using a bandsaw and sawzall, and carefully controlled air flow and ventilation while cutting and shaping, we were able to estimate our needed buoyancy and foam demands for *Hallie*.

We cut *2 units* of **390-cm^3 blocks**, *2 units* of **210-cm^3** blocks, and *2 units* of **280-cm^3** blocks to counteract the 5.9-kg, out-of-water mass of our vehicle. Total volume displacement needed for flotation at the surface was approximately **8.8×10^{-4} m^3** of syntactic foam or approximately ***0.88 kg*** of buoyant force applied in water when submerged.

Occasionally copper pipe insulation, and capped ¾" PVC, were used to tweak pitch and roll difficulties while performing tasks and operating at different depths.

As far as our floatation design is concerned, rather than complicated ballast systems, we decided to get our sub as close to neutrally buoyant as possible, and use vertical thrusters to change depth. For stability, we want to keep our center of buoyancy significantly above our center of mass. The theory here is that the upward buoyancy force would originate above the downward force of gravity and prevent the sub from rolling.

Description of a Technical Feature of the ROV Industry

Syntactic foam remains one of *Hallie*'s best features, allowing her to dive to depths as yet untested. Several years ago Milton Academy's ROV club used pool floats that compressed under the stress of diving and ended up altering the submarines' neutral buoyancy make it difficult to rise to the surface. We struggled to find a replacement for our floatation, but none seemed to present itself. Ultimately, after exploring the dumpster of a local foam-making Canton, Massachusetts company, we happened upon syntactic foam. Such a discovery allows us to dive and surface without worry of compression or distortion.

Syntactic foam's properties—light weight, low thermal conductivity, and resistance to compressive stress—make it ideal for anyone seeking to explore the world's oceans. Syntactic foam's light weight provides several advantages to the ROV community.

Low weight means a favorable power to weight ratio. If a sub is lighter due to syntactic foam, it can increase its payload—a very pressing concern for those in the military or science fields—or it can move more quickly under the same motor.

Low thermal conductivity means that one submarine may be used all over the world, irrespective of the water's temperature or depth. By not heating, the syntactic foam won't expand and allow gas to be trapped in between molecules, thereby affecting its buoyancy. Similarly, because the syntactic foam does not compress, the submarine may be used in shallow or deep waters. The universality of places that submarines with syntactic foam may operate could considerably cut down on costs for

But what makes syntactic foam unique in its properties? In other materials, as the depth increases the pressure in the pockets of air would also increase, placing a tremendous strain upon the submarine's neutral buoyancy. Submarines without syntactic foam often have to design intricate ballast systems to maintain buoyancy.

Syntactic foam, by contrast, operates by using tiny glass microspheres or "microballoons"—tiny hollow spheres of glass, with a micrometer diameter. These tiny spheres are resistant to the compressive forces and therefore don't change their shape when compared against other forms of floatation.

Unbeknownst to us at the time we plodded through the dumpster syntactic foam remains a critical component of undersea exploration, medical research, and deep-sea oil industry, where other foams would implode. Some autonomous submarines, like the one developed by the Chinese government and explained in the September 17, 2005 New Scientist article, "The Race to Revisit the Ocean Depths" by Jonathan Fildes, are built entirely out of syntactic foam. Syntactic foams low weight means that the Chinese submarine may perform more tasks in less time—the goal of every scientist seeking to uncover the secrets of ocean depths.

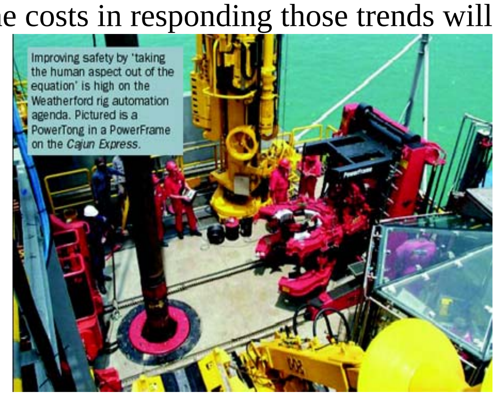
http://en.wikipedia.org/wiki/Syntactic_foam
http://www.newscientist.com/iplogin.ns;jsessionid=JGIJEIILNEPA

DESCRIPTION OF ORGANIZATIONS THAT EMPLOY ROVs

The Twin Needs for ROVs in the Offshore Oil Industry: Exploring the Ocean Floor for New Sources of Petroleum and Maximizing Efficiency of Existing Oil Wells.

This need for an R.O.V. stems from the twin needs of the oil industry to discover new sources of petroleum, while maximizing efficiency of existing wells.[1] In order to keep up with rising consumption, the oil industry must constantly come up with innovative solutions to meet our growing dependence on fossil fuels. While the United States consumed an average of 19.7 million barrels per day of oil in 2002[2], it produced only 42% of its total oil demand[3]. This growing dependence on oil has led to innovative approaches in the industrialized world in order to meet oil demands. Sometimes these innovative approaches include ROVs, which have comfortable niche in the oil industry.[4]

According to Reuben Schilling, current trends in the "offshore oil industry [is] (1) the need to establish oil wells in deeper water, and (2) the pressure of economic incentives to move traditionally platform-based process systems to the sea floor."[5] Intuitively, offshore oil companies that minimize the costs in responding those trends will



Weatherford oil automation machine "Powertong" is one such ROV that takes the human aspect out of oilrig systems.

[1] http://science.howstuffworks.com/oil-drilling.htm/printable
[2] http://www.solcomhouse.com/usenergy.htm
[3] Ibid
[4] www.oilonline.com/ images/news/rig2.jpg
[5] http://www.diveweb.com/rovs/features/uw-sp98.03.htm

grow in production. To the cost-sensitive offshore oil industry, cost-effective, maintenance-friendly ROVs have never looked friendlier.[6]

Divers go underwater to carry out maintenance work on the oilrigs.

To maintain offshore oilrigs, the oilrig industry has had to plan for the building and maintenance of these structures. Clean water for extinguishing fires and use by workers is raised by steel pipes, or cassions, from 20 to 50 meters below the ocean surface. If out of order, these cassions can halt oil and gas production. Until fairly recently, Shell deployed ultra-sound device-carrying divers to check the structural integrity of its cassions in the North Sea.[7] These divers, however, were not very effective as they suffered near constant bombardment by waves and the effects of constant pressure fluctuations as they inspected the cassions. Additionally, the process of inspecting the cassions proved too laborious for the divers as they needed to thoroughly clean the cassions before the ultrasound could give adequate readings. When inspection engineers frequented a pulsed eddy current conference at the yearly Shell Global Solutions, inspiration struck.[8] Uniting pulsed eddy current (PEC) technology with an ROV provided the solution Shell was looking for; within a few years the ROV-PEC system has more proved itself. "The ROV-PEC system is capable of mapping the wall thickness of a caisson in the area a meter or two above and below the enclosed pump in less than an hour. Before it had the ROV-PEC, [Shell] needed a diving support vessel at $175,000/day, and this allowed [them] to inspect up to three caissons in 24 hours. Now he uses a simpler vessel at $70,000/day, ties up only one of the four ROVs it normally carries, and completes six to seven inspections during an eight hour shift."[9] In the offshore oil industry, the future for ROV technology has never looked brighter.

[6] Ibid
[7] http://www.oilonline.com/news/features/aog/20040801.Automati.15380.asp
[8] Ibid
[9] Ibid

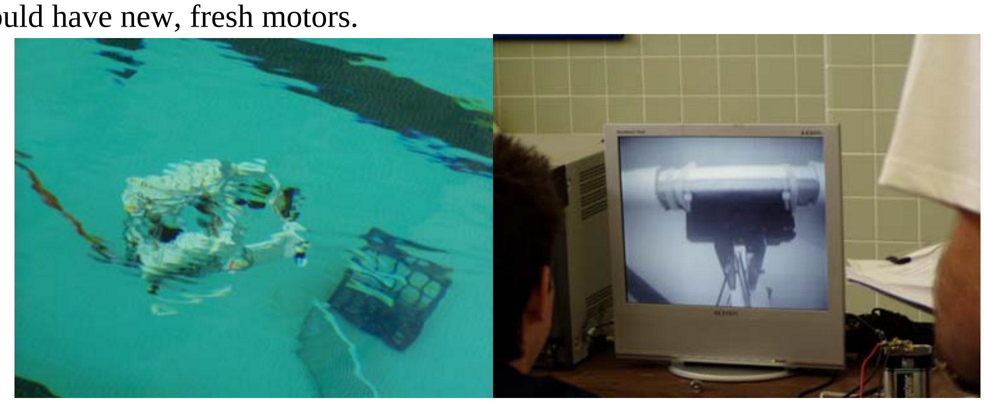
Challenges and Troubleshooting:

There are two missions in the Ranger Class this year. The first mission is to complete the "central node." The mission involves the multiple small tasks of transporting of electronic module, locating the module in the frame, opening the frame door, and finally inserting the submarine connector into one of the open ports on the module. The second mission is to manually trigger the "malfunctioned acoustic release transponder" to release the buoyant instrument package. After looking through the assigned missions and the guidelines, our team determined that while the missions were certainly a challenge, the precision of the gripper system and maneuverability of the sub are the foremost important considerations when successfully completing these missions. Therefore, we decided that instead of using intricate machinery such as a commercial gripper system, an inexpensive gripper and efficient driving of the submarine would fulfill the job. We learned from the original design of the gripper that the gripper with flat surfaces would not provide enough friction for gripping the round surfaces of the power/ communication connector. Instead we decided to use the inside of a rubber bicycle tube to help us grip the 1"- diameter PVC pipe. A small piece of copper rod will be inserted into the gripper to facilitate the grabbing and securing of the pin for the second mission task.

Water Tests, April 2006, @ Quincy, MA. Y.M.C.A.

Whereas the mounting of the gripper was relatively a simple task to complete, the mounting of the motors and cameras proved to be the most difficult aspect of designing. The mounting of the motors and cameras required the configuration that would not obstruct the water flow or the camera view. Effective and yet simple system for driving required for us to mount the four motors in two directions each, giving us total three degree of maneuverability—forward/backward, up/down, and pan—allowing us to drive the sub quickly and efficiently. However, the initial configuration had the motors interfere with the camera-view, while the camera interfered with the water-flow, reducing the motor power. We eventually decided to place one camera toward the front (looking down), and one camera near the rear of the submarine (looking through the submarine from the back). Finally, the cameras were mounted with ball bearing mounts, which made adjusting of the camera view, according to the need in the mission, a lot easier.

At the national competitions the past two years, our vertical motors failed due to leakage caused from the inadequate sealing. Our sealing method lets a small amount of water to be drawn into the area around the shaft. This process allows for corrosion of the motor, a process that can adversely affect our efficiency and rpms. We tried using gearhead motors, which are sealed, but nowhere near as powerful as the 12 V-DC 7800 rpm Johnson motors. Sealing the shaft with hot glue and duct tape was not an option because that would interfere with the rotation of the shaft. Using bilge pump motors was a possibility, but they had significantly less power than our Johnson motors (the bilge pump motors produce 4 ~ 5N of force in water, while our Johnson motors produce 7 ~ 8N). We briefly considered using brushless motors, and therefore less conducive to corrosion however, each motor is very expensive ($50+) and thus we did not use them either. There are waterproofing methods that use marine grease, but all of them require a longer motor shaft. Because most shaft extensions and couplings are produced for larger motors, the shaft extension solutions available for our motors are expensive – extending the shaft of a single motor would have cost around $30 – or $120 for all four motors. And because we did not have a large budget, extending the shafts and waterproofing the motors were out of the possibility. In the end, we chose to seal the motors more carefully and to have separate practice motors and competition motors so that in the competition, we would have new, fresh motors.



New England Regional Competition, May 6, 2006 @ Mass. Maritime Academy

Two years ago, we had used the open-cell foam as floats to assist our buoyancy, but those floats compressed under the stress of the depth. We needed a flotation solution that was light as well as resistant to compression. Since last year, we have used the syntactic foam—at type of close- cell foam that is used in actual deep-sea submarine. We were able to get a free sample—by scrounging around in a Dumpster—and we cut that sample into two long blocks and mounted on the top side of the submarine.

Finding a good tether also proved to be a hard task. Because we wished to make our submarine as simple as possible, we didn't distribute power onboard the sub but on land, on the control box. Therefore, the tether had to carry all of the current used by the motors. We tried using a pre-made audio 'snake' cable, because we thought that we would be able to take advantage of the many conductors in the cable (24 conductors, including shielding wire). However, we discovered the wires were too thin and had far too much resistance to support the current needed for the motors – the wires themselves drew 4 amps at 12V over a distance of 20 meters. Ultimately, we settled on using our previously tested method and paired 18-guage wires and bundled them together with polystyrene foam (for neutral buoyancy) in plastic mesh. We did find alternate Belden lead wire for more flexible tether management.

The control box is an integral part of the maneuvering of the sub – depending on the shape of the submarine, the sub will be easier/harder to maneuver. Because there is one gripper and three separate motor sets to control (left horizontal motor, right horizontal motor, and vertical motors), the entire submarine is controlled with four switches. After looking at various video game controllers, we decided to mount the two horizontal switches near the thumbs, and the gripper and vertical switches near where the index fingers are. Having a controller designed that way means that the entire box can be held in the hands and the submarine can be controlled easily.

As a result of this seemingly endless discussion and experimentation that came from numerous hours of construction and effort, *Hallie* was created, whom we will proudly present at the 2006 International ROV competition.

FUTURE IMPROVEMENTS

Several improvements could enhance the performance of our ROV for future competitions. One that has become an issue is the protection of the ROV's components—such as the camera. For example, because the front camera extends beyond the frame of the ROV, the front camera often bumps into various obstacles and pool walls. The front camera is fastened to the frame by a ball-bearing camera mount, and can be misaligned in a collision with the wall—causing its view to change. We could have put a PVC shroud (of about 4" diameter) around the camera for protection. Perhaps, in span of time between when the judges receive this technical report and the competition, we can build that PVC shroud.

While we tried our best to wrap the foam around the tether so that it would be neutrally buoyant, the tether still creates some drag. When the ROV was near the bottom of a 3-meter deep pool, the entire submarine tended to tilt down due to the forces of drag and lift created towards the back of the submarine. We have tried using pre-made tethers from videoray.com, which are used for some professional ROVs, but we found them too inflexible and too thin of a gauge to carry enough current for our purposes. One way to lessen the burden on the tether and allow wires of larger gauges to be used for the tether would be to use onboard mechanical relays or amplifiers—a Darlington pair would create enough electrical gain to act as a switch—to handle the current distribution. Because the resistance of a wire is related to the inverse of the cross-sectional area of the wire, the thicker the wire, the less the resistance is. Also, a thick wire, with a radius that is twice the radius of a thin wire, has four times as much cross-sectional area, and therefore has a fourth of the resistance – in order to create a low resistance with separate wires, four thin wires have to be used. Therefore, using a pair of thick wire for transferring power, and many thin ones for sending the unamplified signal would be ideal for creating a thin, efficient tether. Two years ago, at the New England Regionals, we talked to a team that used the Innovation First system to control their ROV. Because they had onboard power, that team's tether could use much thinner wire because they were sending electric signals down the tether and amplifying the signals onboard. Such a method would let us decrease our tether thickness and increase our maneuverability. Though as of yet, the technical procedure of how exactly we would develop onboard power with our limited technical skill remains unclear to us.

New England Regional Competition, May 6, 2006, Massachusetts Maritime Academy

The controls on our control box are also non-analog controls, and have no way to vary the speed of the motors. Although we considered installing a rheostat/potentiometer knob that would adjust the speed of the motors, we felt that a separate knob would make driving difficult, and we wanted to use joysticks to be able to have a more efficient control system. After we researched we couldn't find any way to use standard potentiometer joysticks to control both forward and backwards rotation of the motor without using microcontrollers. Some method to implement a variable-speed control system, with joysticks or similarly intuitive controls, would improve the maneuvering of our submarine.

Last, but most importantly, as mentioned before in the 'Challenges and Troubleshooting' section, the waterproofing of the motors is the largest problem we need to work on. At the present moment, we weighed the power and efficiency of a relatively unsealed Johnson motor over the security and speed of a sealed motor. In future submarines, however, we feel that we need to find a definite solution to waterproof our motors without losing too much power.

Massachusetts Maritime Academy, New England Regional, May 6, 2006

LESSONS LEARNED

Although the task of building a remotely operated vehicle is fraught with complications, we remained determined to reach our goals and recognized important lessons in teamwork and practicality. Meanwhile, we focused on elaborating on our skills obtained last year, using all of the tools available to create the best, most efficient submarine. We learned that there are many correct ways to accomplish one task and learned to agree upon which of those was the most practical and the simplest.

Teamwork is crucial. Without it, the competition would lose its meaning. We learned to work with different people from different ethnicities and background. A majority of our team comes from a background in which English is there second language so writing technical reports came to be a challenge, especially in the rush to get our thoughts down. Even though contrasting ideas often led to heated discussion about the future of our submarine's design, this sharing of ideas proved to be crucial in deciding on the best method that would best serve the function of the submarine. We therefore realized the value of co-operation and leadership, how meaningful it is in every aspects of the competition, including deciding on the best designs and dividing the jobs among individuals well suited to the tasks.

Finally, we learned that it takes many ideas and many tests to achieve a final product that is at its best. Sticking with the team's philosophy of KISS, we were driven by the momentum created during all those hours our team spent on the submarine. Ultimately, overcoming all the troubleshooting problems, through methodical and cooperative working toward the creating of final product, was the best experience of this project.

A Portion of the M.A.R.O.V. Team, M.A. Science Building/ Water Tests, Quincy, MA. Y.M.C.A., April, 2006

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Early Prototyping in M.A. Shop Area, February, 2006