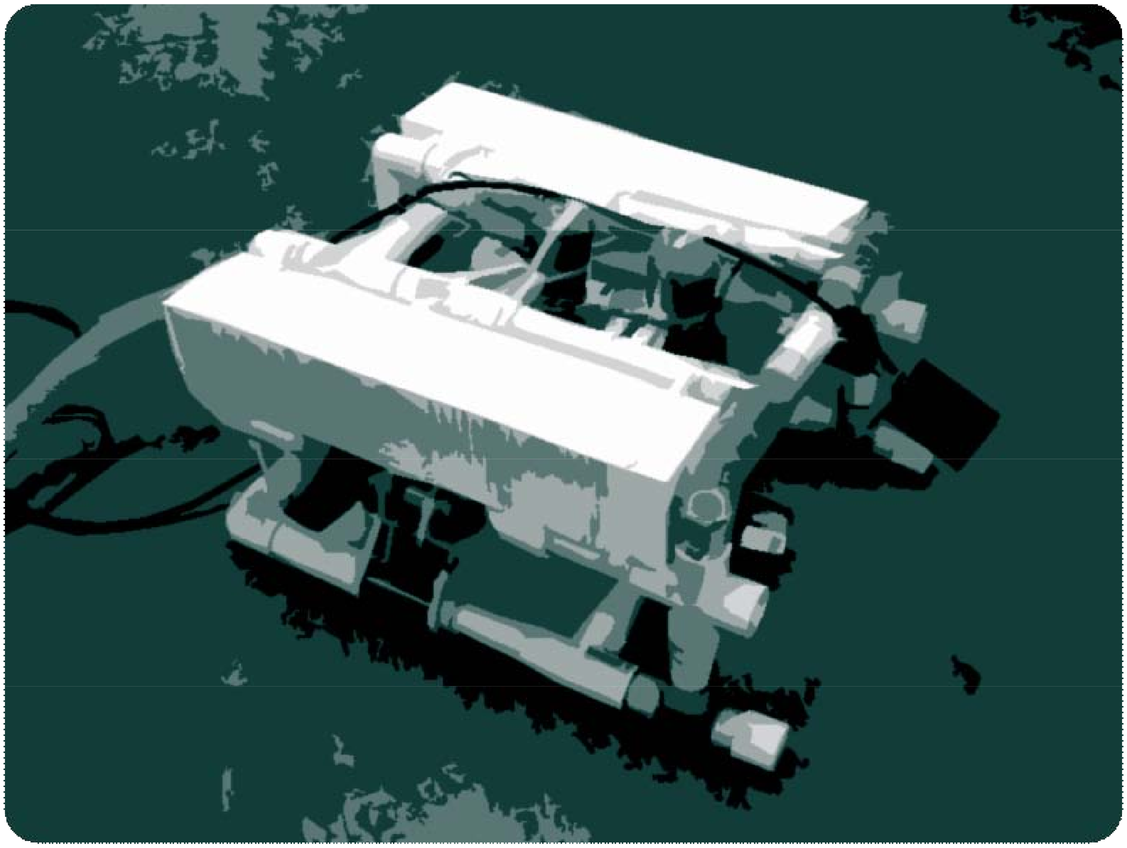
M.A.R.O.V Team Technical Report
ROV- The *Henrietta*



Milton Academy SUB and R.O.V. Team
Milton Academy
2004-2005

Team Members:

Dan Lee (2005)
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ABSTRACT

This technical report encompasses the designs and construction of the *Henrietta*, Milton Academy's Remotely Operated Vehicle (ROV) for M.A.T.E.'s 2004-2005 New England competition at the University of Rhode Island. The *Henrietta*, our response to the 2004-2005 Ranger Mission Tasks, began as the brainchild of seven Milton Academy students united in their collective passion to design, build, and pilot R.O.Vs. Energized by our prior success in last year's New England competition in which we placed first over all, we started upon this endeavor with the aim of continuing that passion as we learned still more technical expertise and trained new members of the team.

Like the influential astronomer Henrietta Leavitt to whose name she pays homage, the *Henrietta* is hardly stranger to adversity. From our earliest glimmer of a blue print to our finished product, the *Henrietta* has been refined and redesigned to counter any challenges she meets while completing her three tasks.

DESIGN RATIONALE

Our submarine was based on the principles of KISS (Keep It Simple and Stupid), and we focused on improving its simplicity, efficiency, and speed.

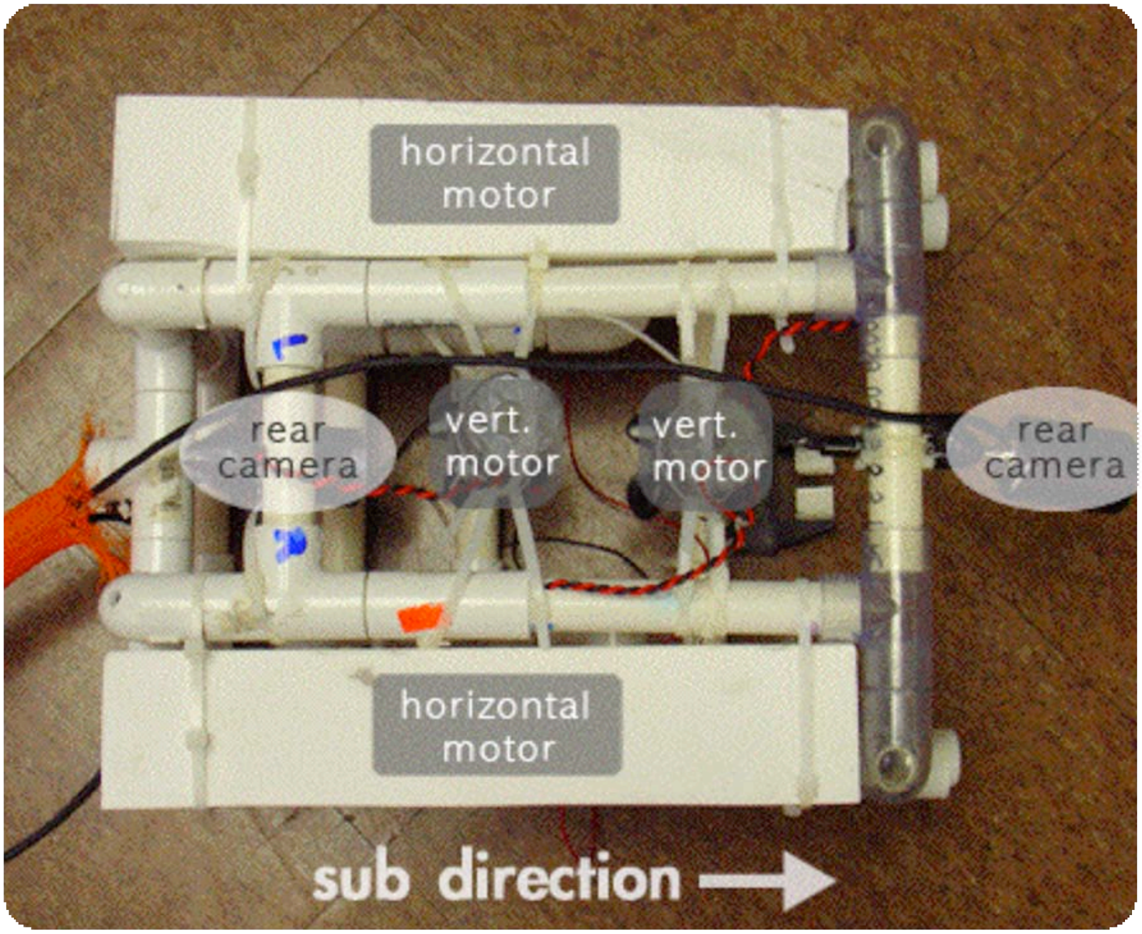
Frame:

For the frame, we designed a box-like frame (the box shape is sturdy and provides space for components within) with PVC 40 piping and joints, three 'layers' of PVC connected by vertical supports around the structure. The sub has two rectangular 'hooks' built-in to the frame and protruding from the front that were built specifically for the ball-valve task. The sub was also designed with the motors in mind, creating an obstruction-less pathway for vertical and horizontal water flow. Because the submarine is not hermetically sealed but open, we did not feel the need to make the sub hydrodynamic.

Motors:

The submarine had four motors total: two vertical and two horizontal. The horizontal motors control the horizontal movement (forward, backwards, clockwise/counterclockwise turning) and are mounted on the outer middle edges of the submarine in order to facilitate turning and to reduce the turning radius. We mounted the vertical motors on the top of the submarine, higher than the center of buoyancy, so that the sub remains upright and stable during 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 descent. All of the motors have a clear path to facilitate water flow.

The propellers are mounted close to the motors, which means that waterflow is restricted when the motor draws water towards the motor, as opposed to the motor – which means that the power of the motor operating in both directions is different. The motors are mounted so that the submarine gains more power for advancing forwards and rising upwards.



After several thruster trials, we decided to fit our submarine with 3-15 VDC Johnson workhorse motors (7800 RPM and $1.75 each!), later matching them with Graupner 3- and 4-blade propellers (50 & 60mm respectively) for the horizontal/vertical thrusters; this allowed efficient current use and optimal thrust through the viscous, chlorinated medium. Tom Gagnon aided both decisions with his previous ROV and lab/field experience.

We waterproofed the motor with sufficient amount of duct tape and hot glue – however, the motors are still prone to leakage. We plan to use one set of four motors for practice and another set of four for the competition in order to assure that the motors for the competition are not corroded. 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 in which the water would conduct electricity. However, recognizing that we are operating within the given specifications of ROV competition, we decided to use this approach rather than that of sealed motors or bilge pump motors. The increase in convenience of sealed motors is compensated by the increase in power and overall efficiency gained by using easily replaceable and inexpensive motors.

Gripper Use and Camera Placement:

Because there were only three tasks, we decided to use one multi-purpose gripper which would reduce the number of wires needed for the gripper. We mounted sections of PVC pipe onto the gripper, so that it would be able to support the module for the space telescope mission and simultaneously hold the fiber-optic cable attachment. The gripper we used was a Lynxmotion gripper originally used with a servo motor; we modified the servo motor to use it as a simple DC motor because all we needed was a simple on/off switch for our purposes. The gripper is located towards the front of the submarine and can be seen by both cameras, from the back and the top.

The cameras are black and white waterproof cameras that are hermetically sealed. Around the front lens of the camera is a ring of 10~12 LEDs that provides low-power infrared 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 the telescope and ‘leaky pipe’ missions. The top camera looks down and would be used for the fiber-optic cable mission.

Tether:

We used an orange sleeve to organize the wires into a single tether and to prevent wires from touching the propellers. Within the sleeve, we ran 12 lines of 18-guage wire wrapped with internal polystyrene foam (for the first 15 feet) to create buoyancy.

Buoyancy:

For buoyancy, we wanted to find a new system this year. We found some problems with the foam insulation tubing we used last year, in that it compressed under the high pressures of the depths at which we were operating. We decided to augment this with blocks of the syntactic foam that many teams swear by. 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, we were only able to use two large chunks of it on either side of the sub. Also, 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. 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 above our center of mass. The theory here is that the upward buoyancy force would originate above the downward force of gravity. For example, if you were to hold a ball on the end of a stick, you would let the ball drop below the stick, so it would hang rather than balancing it in the air.

CHALLENGES AND TROUBLESHOOTING

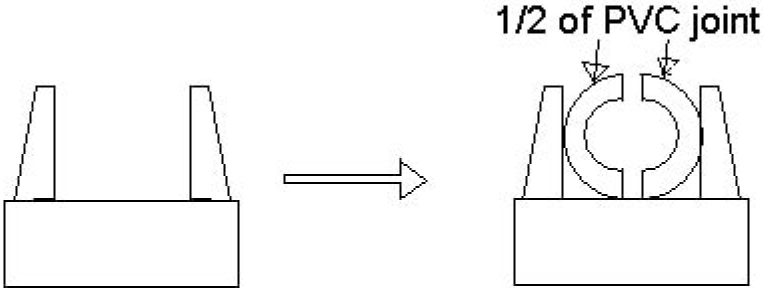
There are three tasks, one of which (the Velcro patch) we had already faced in last year's competition. The other two tasks involved dropping a probe and moving a valve. Initially, after we'd received the tasks and revised guidelines, our team determined that while the tasks were still a challenge, the completion of these tasks depended more on the maneuverability of the sub, rather than complicated gripper systems or intricate machinery – all of the tasks could be completed efficiently by using a single gripper and driving the sub well. Therefore, our main challenge was to make our submarine efficient, maneuverable, and reliable.

Because mounting the gripper was a relatively simple task, the most difficult aspect of designing the submarine was mounting motors and cameras onto our submarine in a configuration that wouldn't obstruct waterflow or the camera view – while maintaining a small footprint at the same time. We wanted an effective yet simple system for driving, and we therefore wanted to mount four motors in two directions each, giving us a total of three degrees of freedom – forward/backward, up/down, and pan – giving us enough maneuverability to drive the sub quickly and efficiently. The placement of the motors tended to interfere with the view of the camera; however, and the placement of the cameras interfered with the waterflow of the motors (reducing motor power) .We eventually decided on a configuration that would place one camera towards the front, looking down, and one camera near the rear of the submarine, looking through the submarine. On missions where the top-down view would not be needed, the camera is quickly adjustable to see a wider forward view. The cameras were mounted with quickly adjustable ball bearing mounts, which made adjusting the camera view easier.

We had previously used open-cell foam as floats to increase our buoyancy, but found out during last year's competition that the increased pressure (1.5X atmospheric pressure at 5m of water) would cause the foam to compress, losing all of its buoyant properties. We needed a flotation solution that was light as well as resistant to compression. After researching various professional and non-professional solutions for submarines, we decided to use syntactic foam – a type of closed-cell foam that is used in actual deep-sea submarine. We were able to get a free sample, and mounted two long blocks on the top sides of the submarine.

At the national competition last year, our vertical motors failed due to leakage created by inadequate sealing -- our sealing method lets a small amount of water be sucked into the area around the shaft. We tried using gearhead motors, which are sealed, but nowhere near as powerful as the 3-15 volt 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, which doesn't have any physical brushes within the motor, and therefore less conducive to corrosion however, each motor is very expensive ($50+) and thus 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. S, so that in the competition, we would have new, fresh motors.

We also made some changes to our grippers. The original flat surfaces of the gripper did not provide much friction for gripping the round surfaces of the Velcro patch handle and the communications probe. Therefore, we cut off the end of a PVC joint in half and stuck each half on each 'finger' of the gripper. When the gripper closes enough so that the two PVC halves touch, we can be sure that the circular parts that we are gripping will be less likely to slip and could be held firmly. We encountered a similar problem when we mounted our gripper onto our sub. We fastened the gripper with numerous zip ties, but again, we ran into the problem of having limited contact between the flat edge of the motor mount and the round surface of the PVC tube, which may result in the gripper slipping. To solve this problem, we cut a notch in the PVC to form a flat surface on which the motor mount could rest.



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.

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, vertical motors), the entire submarine is controlled using 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 endless discussion and experimentation that came from numerous hours of construction and effort, the *Henrietta* was created, whom we will proudly present at the 2005 New England Regional 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.

Using similar PVC shrouds for the motors could increase the efficiency of the motor output. While the Johnson motors we currently are using are very powerful, the shroud would concentrate the water flowing away from the motor into one direction.

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 had a tendency to tilt down because of the drag and lift the tether created on 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 for our purposes.

One way to lessen the burden on the tether, and allow wires of larger gauges to be used for 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 twice a radius as a thin one has four times as much cross-sectional area, and therefore a fourth of the resistance – in order to create that low a 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. At the New England Regionals, we talked to a team that used the Innovation First system to control their ROV. Their tether could use much thinner wire because they were sending electric signals down the tether (they also had power on board, which allowed them to that) and amplifying the signals onboard. Such a method would let us decrease our tether thickness and increase our maneuverability.

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 convenience 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.

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.

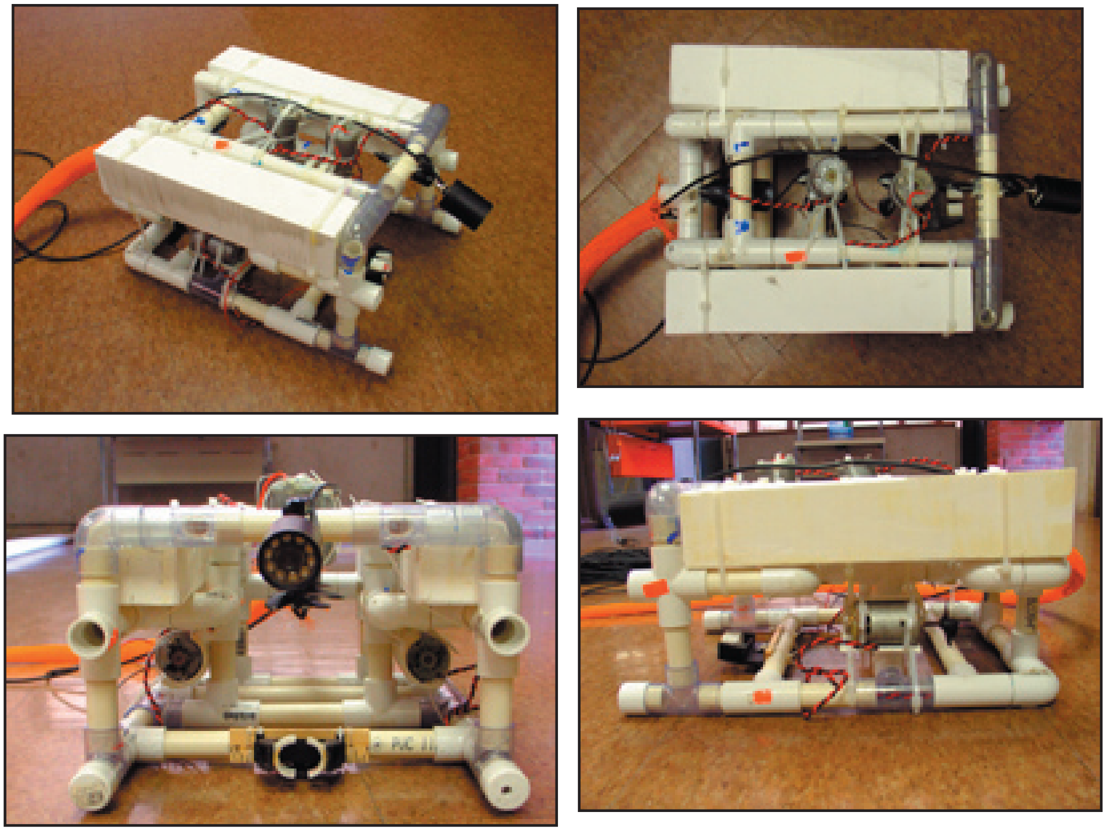
Additionally, this year we elaborated on our skills obtained last year, using all of the tools available to create the best, most efficient sub. We learned that there are many correct ways to accomplish one task and learned to agree upon which of those was the most practical and the simplest.

Teamwork is crucial; without it, the competition loses its meaning. We learned to work with different people from different ethnicities and backgrounds – contrasting ideas often led to heated discussions about the future of our sub, but always resulted in compromise.

The team has also realized that learning from mistakes is critical in the learning process. Some suggestions for the improvement of the ROV were not realized, because they were impractical. Although we hit a few dead ends, which excited feelings of frustration, the team worked through it together, and further helped us understand the value of co-operation.

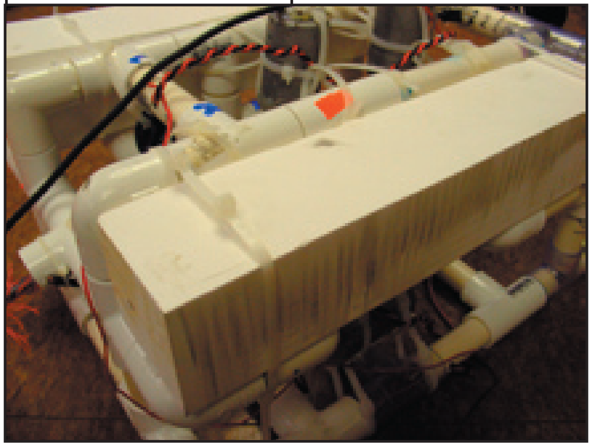
Finally, we learned that it takes many ideas and many tests to achieve as perfect as possible a final product. Sticking with the team's philosophy of KISS, or Keep It Simple Stupid, we were able to create a force to be reckoned with competition time. Ultimately, overcoming a surplus of problems and working towards a functional final product was the best experience of this project.

Pictures of *the Henrietta*

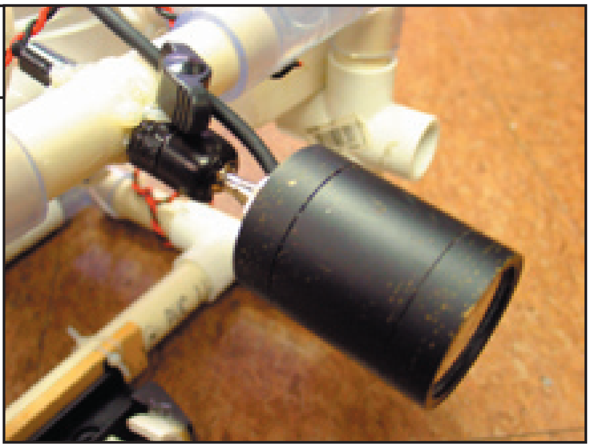


(clockwise from upper right): overall, top, front, side view

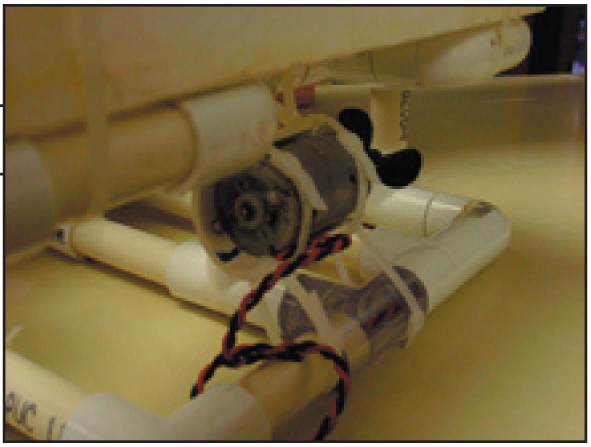
syntactic foam flotation

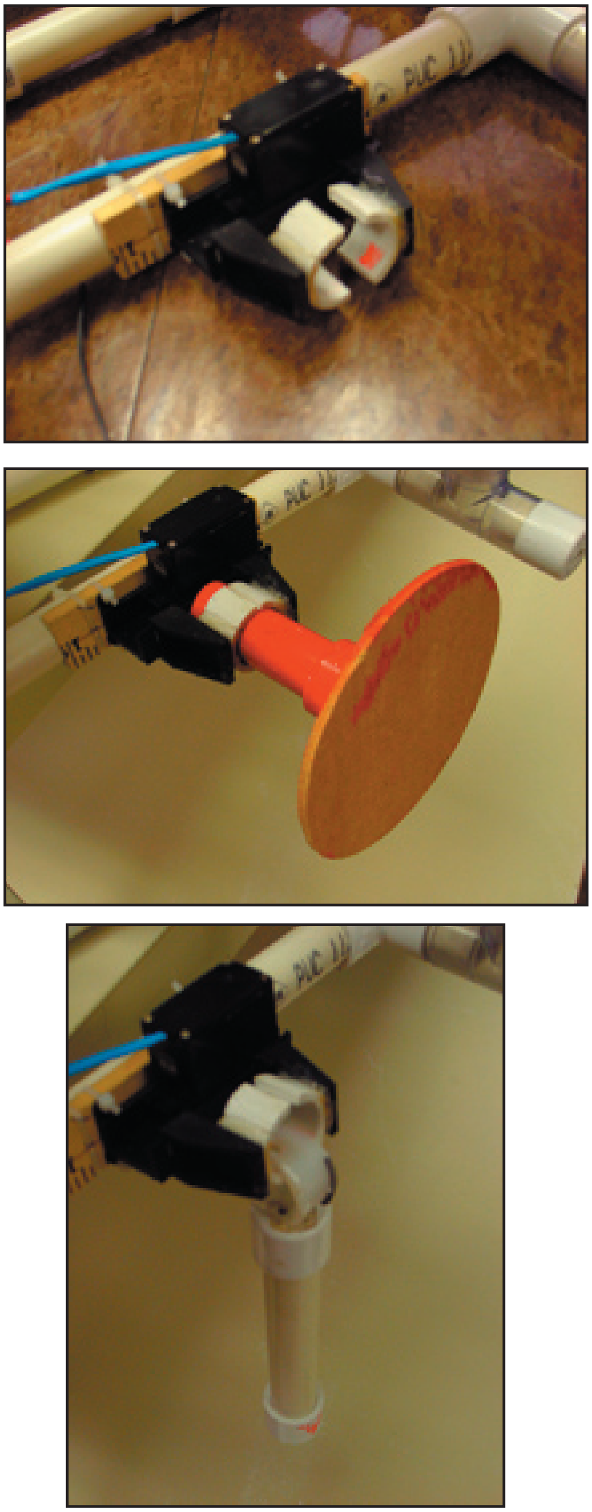


front camera with adjustable mount

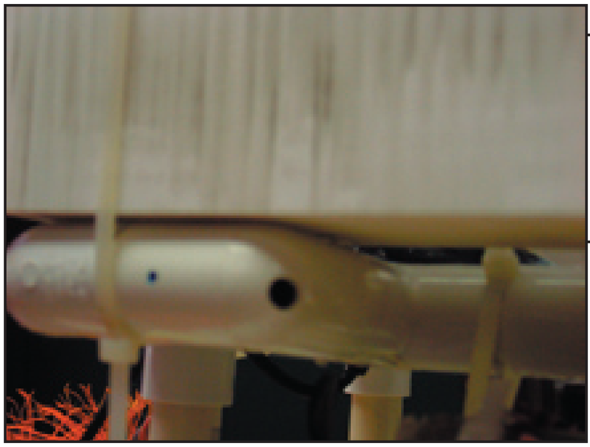


side motors and waterflow space



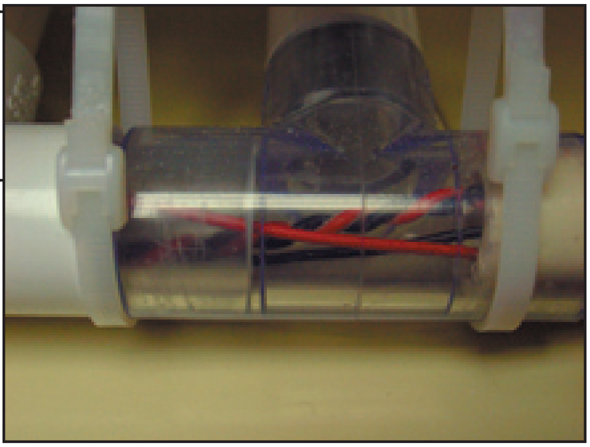


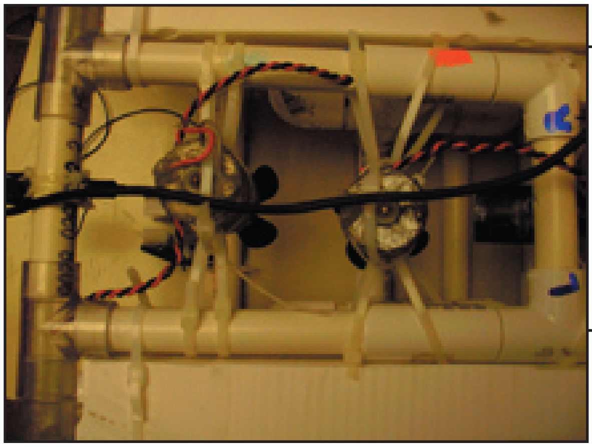
(from top to bottom) gripper with pvc attachment, gripper with telescope module, gripper with fiberoptic cable attatchment



holes drilled in order to allow water to enter the sub, providing stability

cables are run through the frame of the submarine





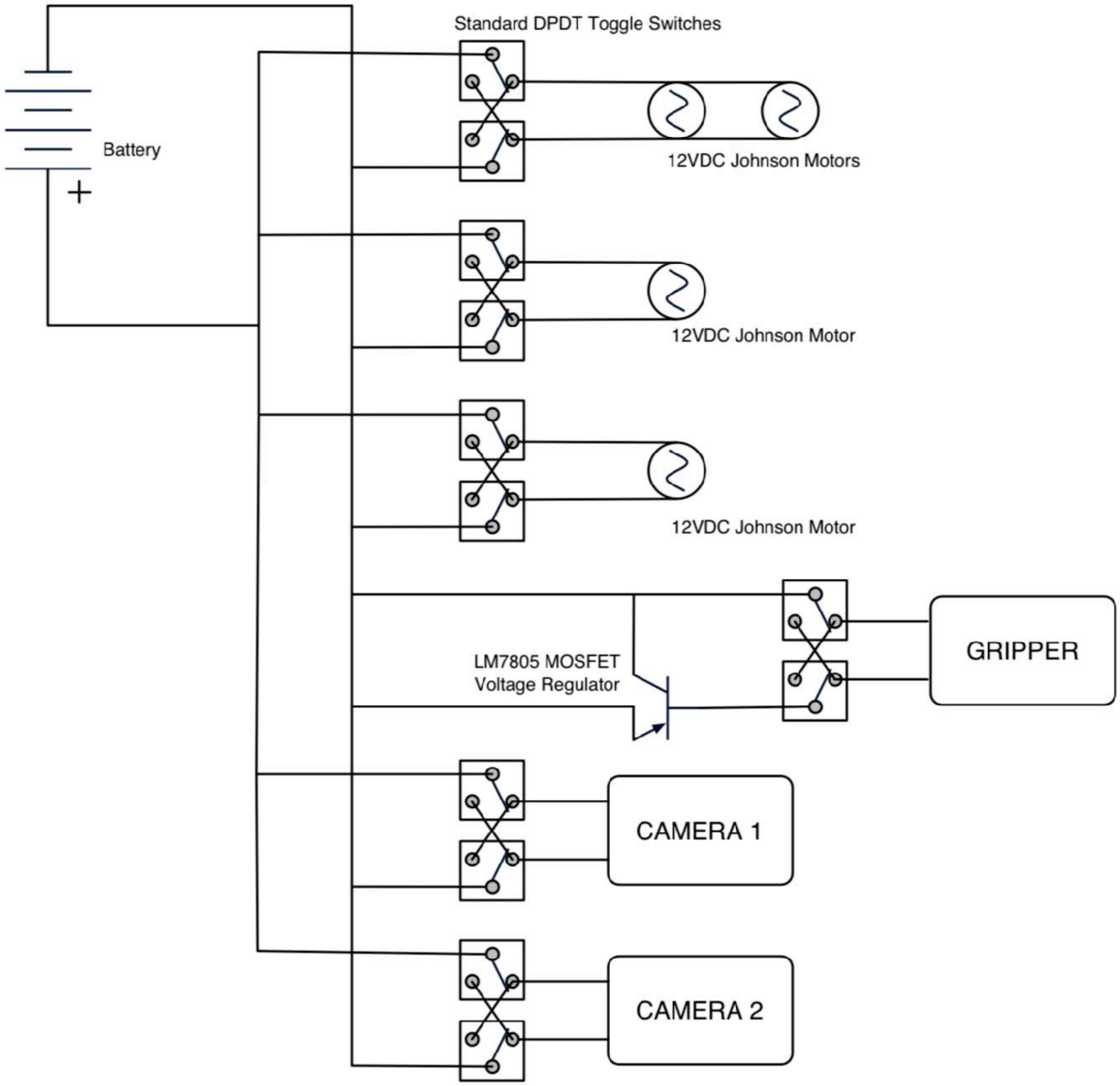
two vertical motors face downwards from the top of the sub to facilitate stable ascent

BUDGET

School Name : Milton Academy
Instructor/Sponsor: Tom Gagnon
Funds

Materials Description	Qty	Unit Price ($)	Cost ($)
Camera (Pro-View CVC 321 WCP)	2	110.00	220.00
Sleeve for Tether Management	1	30.00	30.00
Epoxy Adhesive	2	4.00	8.00
Lynxmotion Grippers	1	15.00	15.00
Lynxmotion Servo Motors	1	15.00	15.00
PVC Fittings		11.00	11.00
Schedule 40 PVC 3/4”		14.00	14.00
R.S. Project Box	1	4.00	4.00
Fuse Holders – Heavy Duty	2	6.00	12.00
Fuse Holders – In line	2	4.00	4.00
Vanco Fuse Holder	2	3.50	7.00
Hot Glue			12.00
Johnson 12 V DC motors 7800 RPM	8	2.50	20.00
Graupner Propellers 50mm/60mm	many		28.00
R.S. Project Box	1	4.00	4.00
Assorted Cable Ties		30.00	30.00
Jameco Switches	many	17.00	17.00
Materials for Mock-up			14.00
22 gauge wire			22.00
25 amp fuses			5.00
		Total	$492.00

SCHEMATIC


Standard DPDT Toggle Switches
Battery
+
12VDC Johnson Motors
12VDC Johnson Motor
12VDC Johnson Motor
GRIPPER
LM7805 MOSFET
Voltage Regulator
CAMERA 1
CAMERA 2

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.

Our Ranger-class ROV, the *Henrietta*, mirrors her cousins in the oil industry by completing her first Ranger task—capping oil wells which are no longer lucrative to continue operations. This need for an ROV 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 grow in production. To the cost-sensitive offshore oil industry, cost-effective, maintenance-friendly ROVs have never looked friendlier.[6]

Improving safety by 'taking the human aspect out of the equation' is high on the Weatherford rig automation agenda. Pictured is a PowerTong in a PowerFrame on the *Cajun Express*.

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

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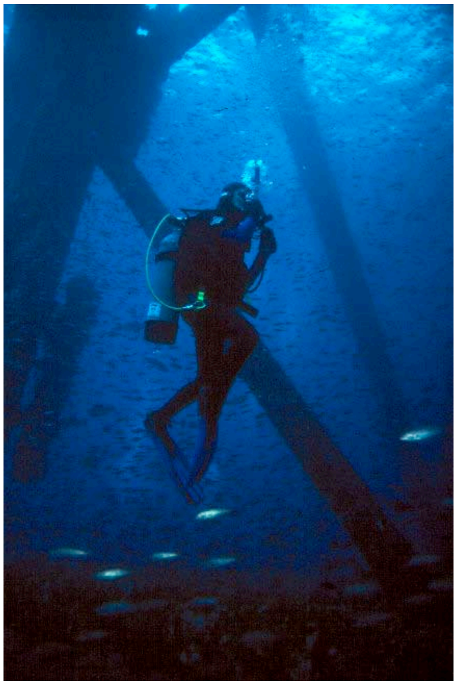
[1] http://science.howstuffworks.com/oil-drilling.htm/printable
[2] http://www.solcomhouse.com/usenergy.htm
[3] Ibid
[4] www.oilonline.com/ images/news/rig2.jpg
[5] http://www.diveweb.com/rovs/features/uw-sp98.03.htm
[6] Ibid

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.

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

[8] Ibid

[9] Ibid

ACKNOWLEDGEMENTS

Milton Academy would like to thank M.A.T.E and Jill Zande, Deep Ocean Exploration and Research (DOER), Marine Technology Society ROV Committee, NOAA's Office of Ocean Exploration, and all other sponsors for their collective effort to organize the 2005 ROV competition. We would especially like to thank Jill Zande, for she has always graciously taken time out of her busy schedule to answer our questions.

We would also like to thank the organizers of the New England Regionals, Brennan Phillips, and all the other teams for their hard work and providing us with an invaluable learning opportunity.

Blue Hills Technical High School and Athletic Director Paul Tourney have generously allowed us to use their pool so that we may test and practice maneuvering our submarine. We heartily thank them.

Our gratitude also goes out to the Milton Academy Science Department and former teammate Albert Kwon, who have been very supportive of our efforts through their helpful advice and the use of the tech shop.

Last but not least, a big thank you to our mentor, Tom Gagnon, who has motivated and seen us throughout the whole ROV construction process.

Milton Academy ROV team members