Milton Academy ROV Team

Technical Report

June 10th, 2004

Milton Academy ROV Team

Milton, Massachusetts

Team Members:
William Joo (12)
SeoHyung Kim (10)
Albert Kwon (12)
Daniel Lee (11)
Fred Lien (12)
Samuel Minkoff (10)
Andrew Oates (11)
Matthew Schoen (10)
Megan Smith (10)
Alice Tin (10)
HsingYu Tsai (11)
David Wu (11)
Louisa Zhang (11)

Mentors:
Tom Gagnon
M.A. Science Department

Abstract

M.A.R.O.V. '04 has had a productive year with the designing, building, and testing of their underwater vehicle for M.A.T.E.'s 3rd Annual National R.O.V. Competition. With the recruitment and addition of new team members in '04, the above stages of our work in preparing for Mystery Reef required continuous collaboration and effective team work to efficiently design and construct our vehicle.

After a successful showing at the University of Rhode Island at the N.E. Regional Competition, there was still more work to be done and improvements to be made. With new wiring, control box schematics, an additional vertical thruster, thruster waterproofing, a new camera, tether buoyancy modifications, and ROV design structure changes, the ROV was nearly completely overhauled for the National Competition. A new alliance with Blue Hills Regional Technical High School allowed us pool practice time and the continued support of Jill Zande, M.A.T.E., M.T.S., and Milton Academy's Science Department gave us financial support and shop space to complete our work.

Eight student team members will travel to UCSB in June. Interest and support have been growing at our school and our team members comprise a diverse set of backgrounds, talents, and personalities. Our on-campus fund raisers, after-school and weekend work sessions, and our overall team efforts have given us a working vehicle that we can take to Santa Barbara with pride. Our increased understanding of the process of design engineering and the acquisition of these required skills have been fundamental to our work this year.

Design Rationale:
While designing our sub, we focused on efficiency, speed, and simplicity:
Frame:

We chose to construct a rectangular frame with standard schedule 40 PVC piping – the rectangular structure lends strength and stability, while also simplifying ballast/trimming issues and providing the most space for the motors, cameras, and grippers; PVC piping was inexpensive and easy to modify, thus allowing more freedom for experimentation in our design.

Motor Placement:

We placed a vertical motor towards the very top of the submarine so that the point of thrust would be higher than the center of buoyancy, allowing the sub to remain upright during ascending vertical maneuvers – after regionals, we added another vertical motor to facilitate vertical maneuvering. Two horizontal motors were placed on the outer sides for maximum rotational capability (smaller turning radius).

Gripper Use and Camera Placement:

The grippers and cameras were strategically placed on our ROV after much discussion and forethought. We contemplated using at least one of the grippers to simply transport and release the tags on the reef structure. Ideally we needed one of the cameras to be able to allow us to see the tag and the mussel bed/tubeworm structure simultaneously to insure proper placement.

The grippers had a fairly limited draw (< 1 amp) on our amperage limits and so we used a zener diode, capacitor, and resistor circuit to power the 4.5v gripper motors. Because of this successful voltage regulator scheme for the control box, we decided we would use 3 Lynxmotion grippers. Two of the three grippers would be used for transporting and tagging the structures on Mystery Reef. One of our cameras would be used to view the operation of our two downward-facing grippers and environment directly underneath our ROV.

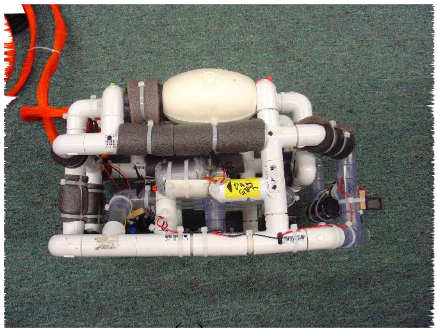
The 2nd camera was positioned to give us a front panoramic view of our underwater surroundings as well as a view of our forward-facing gripper. This 3rd gripper would be primarily used for transporting our connecting line-and-hook assembly for the towfish, patching the leaking barrel, and collecting fish and rock samples.

The 3rd gripper was also outfitted with an extender made from a portion of a wooden ruler which gives us more surface area to grasp objects and a better chance for success with the fish and the rock samples. The extender fits neatly into the groove on the outside of the gripper arms and can be easily removed when needed to avoid entanglement in close quarters.

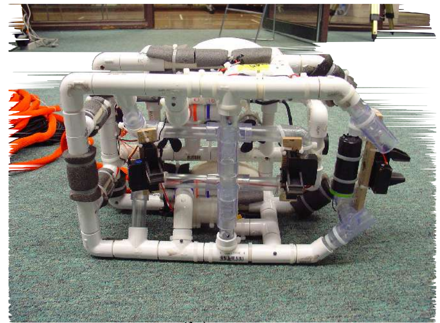
In summary, the 2 cameras and 3 grippers are positioned to allow the best use of space and vision for the challenges of the competition.

Tether:

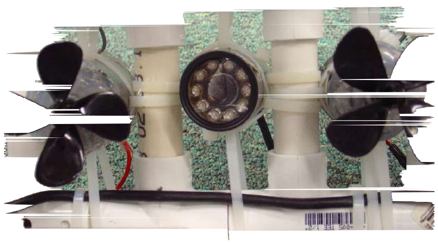
We used an orange sleeve to organize the wires into a single tether and prevent wires from touching the propellers (See Fig. 1.2). At regionals, we used external polystyrene foam to give the tether just enough buoyancy to prevent it from either remaining at the surface or dragging against the ROV. During the regional competition, however, the floats caught on the opening of the U-boat and in the coral reef, making it hard to maneuver the submarine. Our team modified the tether accordingly for nationals, rewiring it to incorporate the additional motor and also feeding foam *inside* it for the first 15 feet to prevent the tether from catching again.



(a)



(b)



(c)

Fig. 1.1 In order from a~c: A side view, a bottom view, and a view from inside the submarine.

Fig 1.2 The tether; all wires leading from the submarine were fed through this orange sleeve along with polystyrene foam, coiled around the wires, for buoyancy.

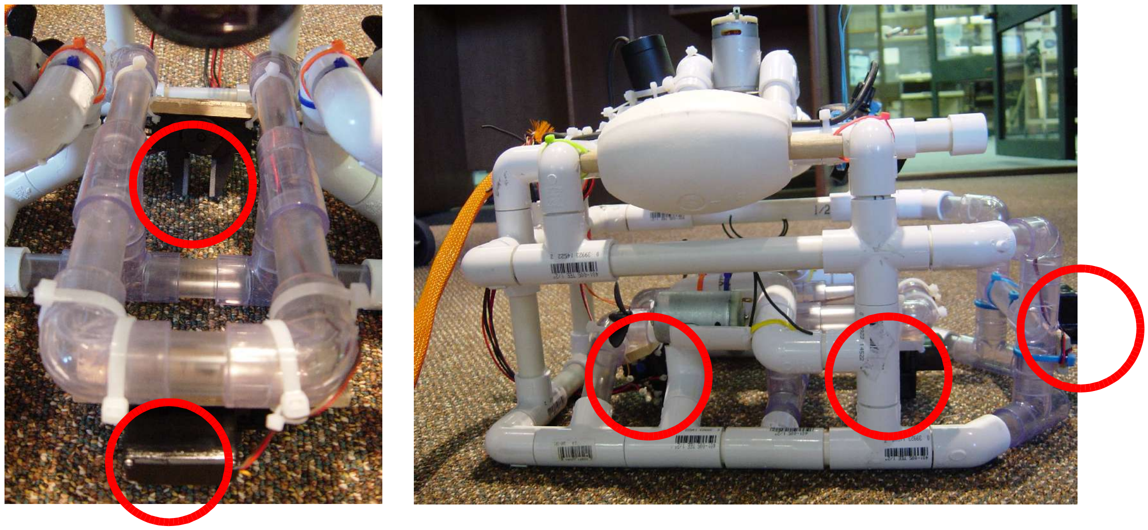


Fig 1.3 Inside/side views of the submarine. The circles indicate gripper positions.

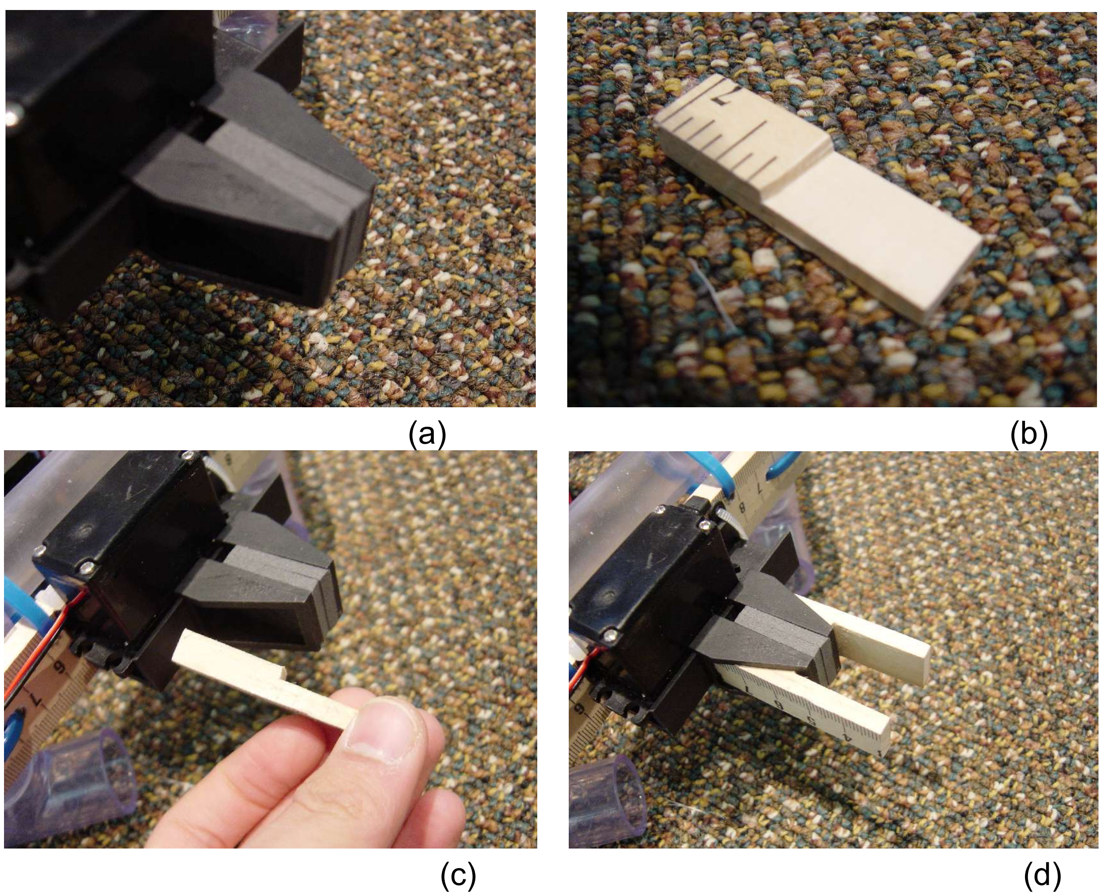


Fig 1.4: Example of attaching extension arms (a->d); we can design any extensions that serve different purposes on to these pieces of wood.

Challenges:

Our entire team debated different methods of collecting/moving objects and controlling the vehicle. Expanding on the experience we gained last year, team members offered a wide and conflicting range of ideas: we considered suction, retrieval arms, active flotation devices and robot grippers, while keeping in mind respective voltage and amperage properties. We also considered the control/wiring problems in each option.

As mentioned before, we wanted an effective yet simple system – one of our most significant challenges was determining the most efficient placement and number of cameras & grippers, while keeping in mind our voltage and amperage restrictions. Our team carefully considered different gripper/camera configurations, finally settling on the one discussed in the design rationale above because of its optimal use of visuals and space.

To account for the different types of jobs required to complete the ROV, we divided into smaller groups to reach our goals: during April, one group wired the control box and crafted the tether, while another group constructed the frame, later mounting cameras and motors on it; we consistently improved frame design and repositioned grippers / cameras as the competition approached – actual testing did not begin until the weekend before regionals. In June, we overhauled the submarine and made finishing touches in preparation for the national competition.

The restrictions put on the size and power availability of our vehicle were:

Size: must fit through the opening of the U-boat
Power: 12 V battery limit
25 Amperage limit
Time Frame: Needs to be completed within by May 8th, 2004 for N.E. Regional
@ the University of Rhode Island.
Budget: $500 spending maximum.

After several thruster trials, we decided to fit our prototype with 3-15 VDC Johnson workhorse motors (7800 RPM and $1.75 each!), later matching them with Graupner 3- & 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 R.O.V. and lab/field experience.

Budget & Expense Sheet: 2004

The following is a list of materials and prices as requested by the MATE regional ROV committee:

Materials:	
Fuse Holders – Heavy Duty	$6.00
Fuse Holders – In line	$4.00
Vanco Fuse Holder	$3.50
8 A Fuses	$5.00
Bus Fuse	$5.50
18 gauge Hook-Up R/B Wire	$30.00
22 gauge Wire	$24.00
Epoxy Adhesive (2)	$8.00
Silicone	$12.00
Schedule 40 PVC 3/4”	$14.00
Transparent Schedule 40 PVC 3/4”	$36.00
PVC Fittings	$11.00
Transparent PVC Fittings	$38.00
Pro-View CVC 321 WCP (Camera)	$110.00
Johnson 15V DC Motors 7800 RPM	$22.00
Graupner Propellors 50mm/60mm	$28.00
R.S. Project Box	$4.00
DPDT Jameco Switches	$17.00
Jameco Toggle Switches	$15.00
DPDT Momentary Rocker Switches	$10.00
Lynxmotion Grippers	$45.00
Lynxmotion Servo Motors	$45.00
Cable Ties	$36.00
Sleeve for Tether Management	$30.00
Tags & Patch Materials	$14.00
Materials for Fish/Sinkers	$18.00
Materials for Tow Fish	$15.00

Troubleshooting:

Through Paul Tourney, we were able to use the Blue Hills Regional Technical School (Canton, MA) swimming pool for testing prior to both regionals and nationals. We finished some important fine-tuning and camera/motor tweaking during both practice sessions.

We expect that much work will be needed on fine-tuning our center of gravity and center of buoyancy. For regionals, we spent lots of time adjusting the amount of floats at specific parts of the vehicle to achieve stability and appropriate buoyancy.

Adjusting the placement of motors and propellers was also crucial. For easy, stable, and well balanced maneuverability, we expected that the placement of the motors would be a big factor.

In addition, we performed a ‘deep end’ test to confirm that our vehicle can ascend from deeper depths given our design and ballast; our buoys were adjustable so that our pitch can be modified at anytime as shown in our pictures.

Our grippers were tested for their responsiveness and we laid out plans on how to approach objects, pick them up, transport them, and eventually "drop" them.

We also needed to make adjustments on our tether to allow for ‘better drag’ and allow for it float at the surface perhaps 20-25’ away from exiting the ROV.

The wiring of the control box also went through many design stages because we had trouble converting 12 VDC to 5 VDC. However, after considering voltage divider circuits, voltage step-down converter circuits, and using a transformer (DC → AC converter), we decided to use the voltage step-down converter circuit due to its simplicity.

For nationals, we needed to repeat center of gravity / buoyancy tests as well as tether adjustments - the extra motor will undoubtedly affect buoyancy and balance. As before, we will conduct tests at the Blue Hills Regional Technical School.

Final Design:

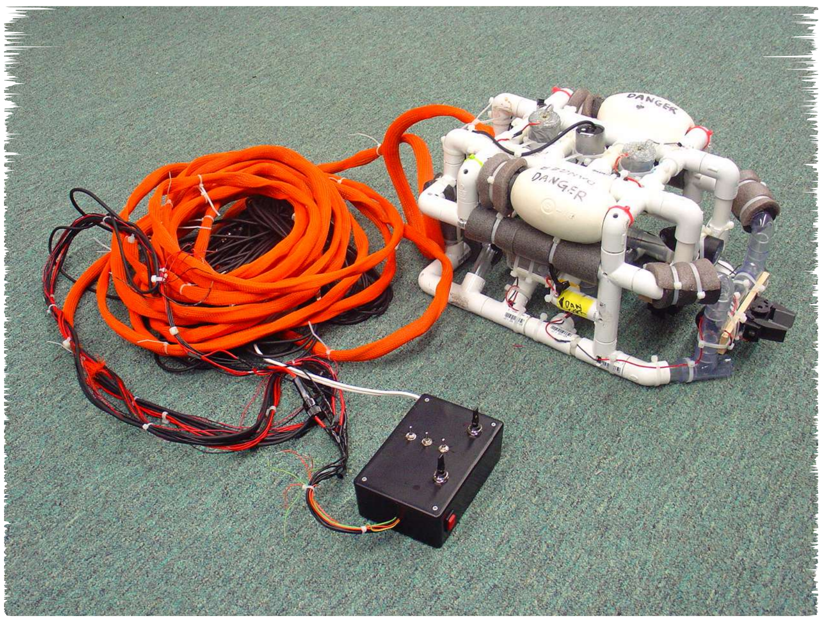


Fig 1.5: (Overview) Milton Academy’s ROV, tether, and control box – our vehicle is equipped with three grippers, two vertical thrusters, and two horizontal thrusters

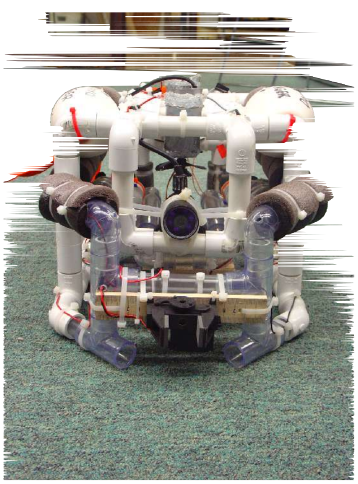


Fig 1.6: Frontal view of our R.O.V.

Our grippers were recommended by Aaron Dollar, a Harvard University graduate student currently working on bio-mimicking robots and robotic grippers. In consultation with Dr. Tom Consi of the M.I.T. Ocean Engineering Teaching Lab, we were also given numerous suggestions about which types of manufacturers of grippers/arms to investigate. We settled on grippers and servo-motors from www.Lynxmotion.com. These grippers were easily mounted and provided us with a low-amp. (~.1 A), low-voltage (~4.5) opportunity to install multiple grippers for the various tasks involved in this year's challenges. They also allowed us to attach extended arms for larger surface area and better capabilities to capture fishing line, rock samples, and carry tags.

For the motors we used $2.95 Johnson high-torque robotics motors and sealed them with duct tape, silicone, and hot glue. While we performed some early testing with Flexane 80 and Plasti-Dip material – both of which would be more permanent than our solution – we were concerned about long term performance and excessive heating (natural water cooling was sufficient, as demonstrated during regionals). We may not have longevity with these motors, but we do save time and money. We have mounted a few more 50 mm & 60 mm RC boat motor propellers manufactured by Graupner (3- and 4-blade propellers) on spare motors to have available just in case our present motors fail.

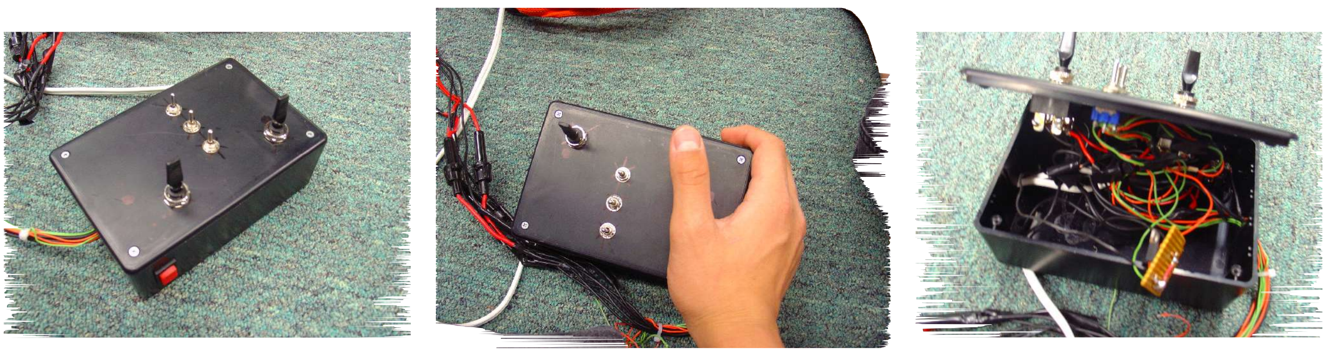


Fig 1.7 Control Box and its inside circuitry and wiring

Our control box, from Radio Shack, has three toggle DP/DT switches wired to give us Open/Off/Close for each of our grippers. Two more toggle DP/DT switches are wired to control the left and right horizontal motors and provide Forward/Reverse/Turn L/Turn R movement, and another momentary rocker DP/DT switch mounted on the front of the control box provides Up/Down vertical movement. The motor controls are mounted so the operator will be able to control vertical and horizontal movement simultaneously with one grip (unlike our previous control box, which placed the vertical motor switch on the top of the control box and therefore required the control box to be controlled quite uncomfortably with the ring and little fingers as well as the thumbs).

We have drilled numerous 0.25" holes in the frame and threaded the wires through the PVC frame wherever applicable to allow for maximum visibility. We left the holes intact because we wished to fill the frame with water – a vehicle with its frame filled with air would be unstable and unwieldy. Thus, we decided to stabilize the vehicle with water and counter the extra weight with foam.

We have done what we can to organize and contain the tether by putting all the wires through an orange sleeve; we also plan to have a tether-management team on site to help us reduce tether drag during operation.

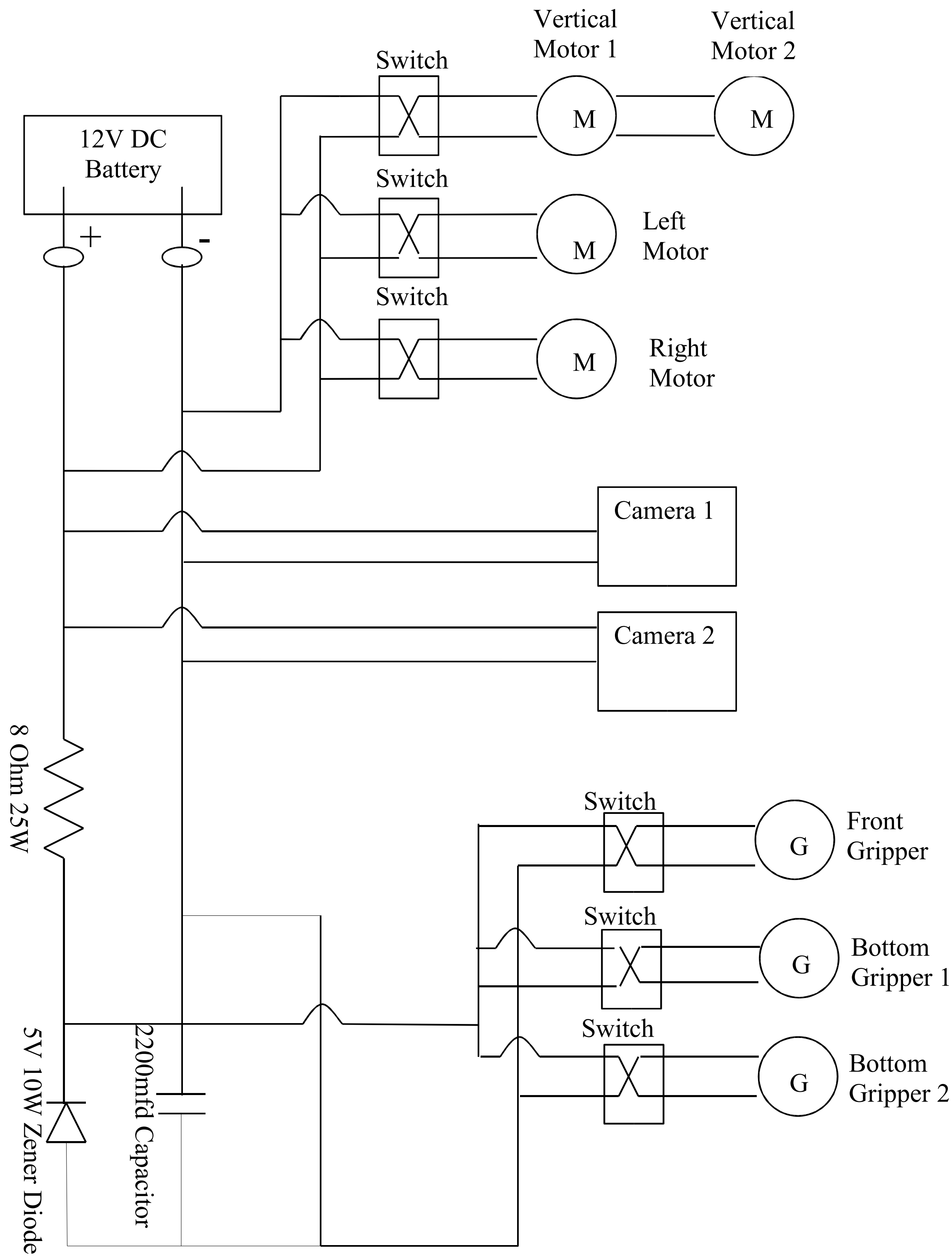
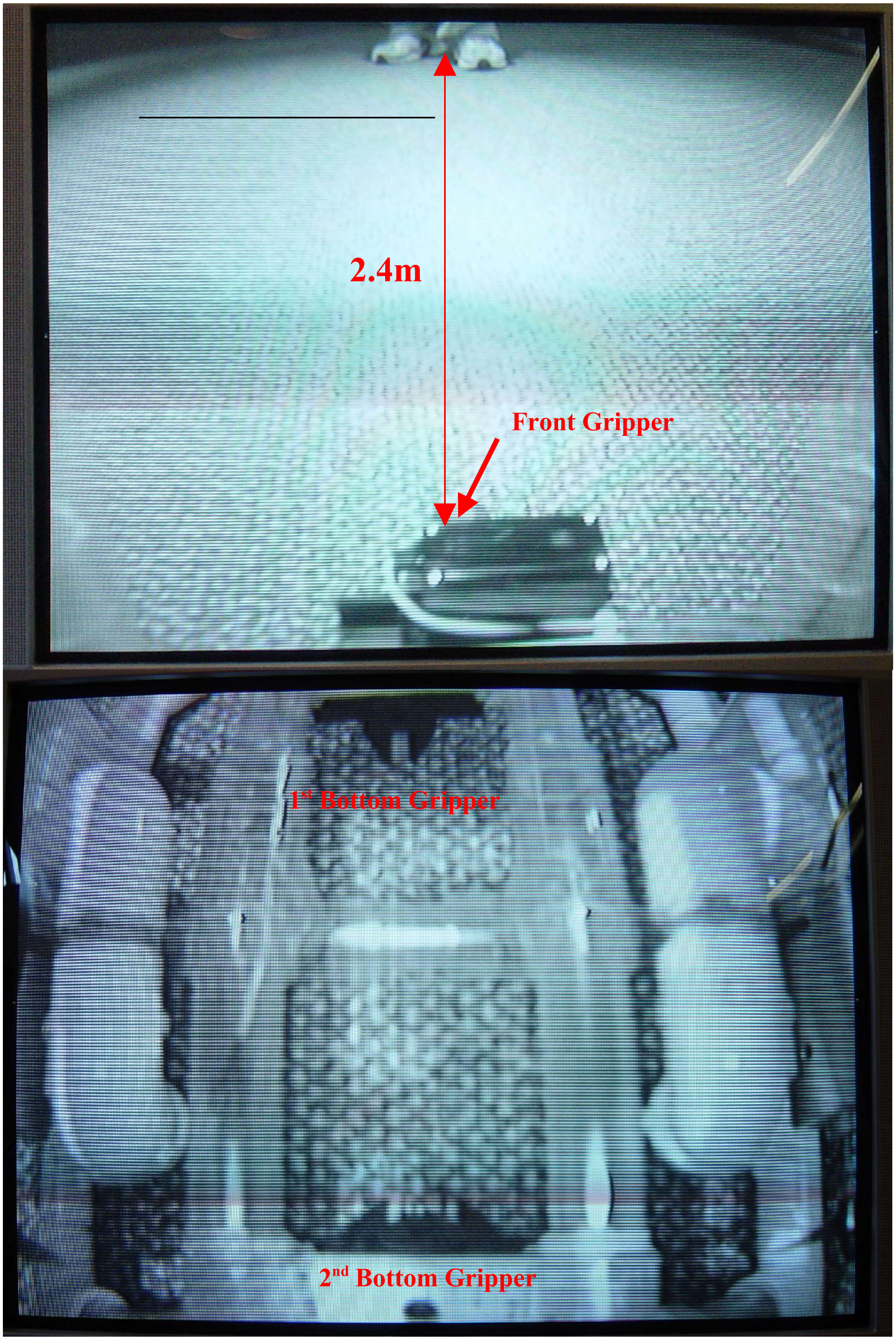


Fig 1.8: Electrical schematic sheet of our control system

Fig. 1.9 Camera views (Front and Bottom respectively)



What we would have done…

A finer control system with better speed and directional regulation would have been preferable. For instance, we could have added a potentiometer or a rheostat to regulate the speed of the sub. In addition, wiring the two vertical motors separately would have given the ROV yaw/pitch capability (which would in turn increase gripper control), while small adjustments in balance and motor position could have improved stability.

Had we crafted a rotating assembly for the bottom grippers, we could have facilitated pick-up and drop-off of target objects (ex: bucky balls→ mussel/tubeworm bed, rocks).

A camera with pan and tilt ability could have given us a wider view and a better sense of orientation. Lastly, better flotation devices could have helped us with vertical movements, perhaps allowing us to hover at the same depth rather than constantly nursing the vertical motor.

Lessons Learned:

Although building a multi-tasking submarine was fraught with complications, we remained determined to reach our goals and recognized important lessons in teamwork and practicality. 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.

Additionally, we explored the basics of marine vehicle design and control box construction, while also learning how to use the tools needed to craft our vehicle. In terms of our ROV we learned that balance and tether drag are important factors; we did not anticipate their drastic effect on movement.

At the beginning of this project we all had designs for highly impractical but “cool” subs, but realized that what we really needed was a sub that would accomplish the task simply and efficiently. Ultimately, overcoming a surplus of problems and working towards a functional final product was the best experience of this project.

How ROVs are used to explore and understand our national marine sanctuaries on coral reefs:

Coral reefs are found in the clear and warm waters of tropical oceans; they are directly connected to the marine environment as they function as food sources, shelter for marine creatures, and terrain stabilizers. Creatures from thousands of species congregate around the reef; in some places the plankton is so thick that movement is unnecessary for consumption. In several regions such as the western Indian Ocean or the Florida Keys, coral reefs support large sectors of the country's populations through tourist development and fisheries. Four million tourists visit the Florida Keys contributing over $1.2 billion to tourism-related services every year; In American Samoa, coral reefs supply over 50 percent of the fish caught locally for food.

Because coral reefs serve important ecological (and economic) roles, detailed research and understanding of the reefs and its environment is necessary. As coral reef organisms can only tolerate a narrow range of environmental conditions, reefs are easily damaged and destroyed by ecological changes or human induced hazards.

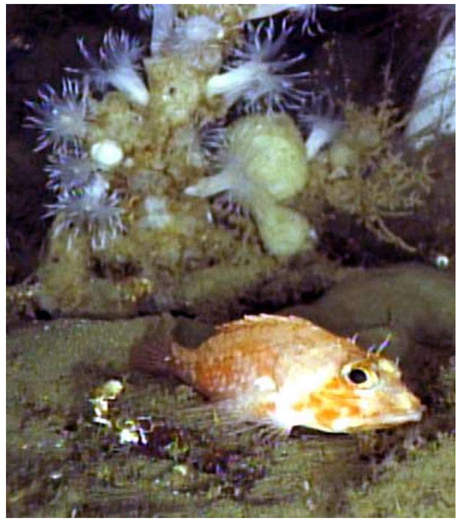
In order to research coral reefs, a non-destructive, non-intrusive method of sample collection and identification is needed. Underwater ROVs (remotely operated vehicles) are adept for the job because they can withstand deep pressures and have multiple cameras and sensors as well as sampling devices for capturing specimen. ROVs can collect and record data such as temperature, depth, GPS location, water current, conductivity, and pressure as well as record video or take pictures; all without the risk of the risk and cost of diving and the possibility of diver-induced coral reef damage.

ROVs have already been used for the research of coral reefs in the Northern Gulf of Mexico. In 2003, University of Alabama, the Marine Conservation Biology Institute and NOAA's Flower Garden Banks National Marine Sanctuary collaborated on a twelve-day expedition to document the presence of deep water coral communities and the use of deep water corals as habitat for other marine organisms. Because the expedition revolved around the identification and classification of marine communities, the ability to collect specimens was critical. Thanks to the ROV, they recorded over 50 hours of video, collected several hundred specimens, and mapped 280 square meters of the ocean floor.

Forty years have passed since the first ROV *Alvin* explored the depths of the ocean. As technology progresses, an increasing number of marine research programs are utilizing ROVs for data and specimen collection – the marine biology community should expect groundbreaking ROV contributions in the future.

Resources

http://oceanexplorer.noaa.gov/explorations/03mex/logs/summary/summary.html
http://www.hboi.edu/news/features/oculina.html
http://oceanica.cofc.edu/Oculina2003/DailyLog/30.htm



The scorpion fish's brilliant color sets off the more muted hues associated with the mound of anemones and sponges in the background. Image courtesy of University of Alabama and NOAA OE.

A red gorgonian on deck. Image courtesy of University of Alabama and NOAA OE.

The Innovator ROV used on the Gulf of Mexico expedition. Image courtesy of University of Alabama and NOAA OE.

Acknowledgements

Milton Academy ROV Team would like to thank M.A.T.E., Jill Zande, Tami Lunsford, M.T.S., Stellwagen Bank Marine Sanctuary, the University of Rhode Island, and all other sponsors of the Regional and National R.O.V. Competitions for making this year's competition possible. We look forward to working on next year's tasks and challenges for 2005!

We would like to thank Aaron Dollar from Harvard University, Prof. Oh-Kyong Kwon from Hanyang University in Seoul, Korea, David Low from the Sound School, for his technical advice and positive encouragement, and Edd Spidell from the Cranston Area Technical High School in RI, for helpful technical advice and suggestions for parts & pieces!

We would like to thank the M.A. Science Department for their helpful advice and use of their tool shop and various materials (and perhaps we can soon bring it back to some order.) The use of the underwater cameras from M.A. Science Faculty Robert Tyler and student colleague Leonard Mazzone.

Also, we thank Blue Hills Regional Technical High School and Athletic Director Paul Tourney for generously allowing us to use their pool for testing and practicing.

A final thank you to M.A. Science Faculty member Tom Gagnon, our mentor, for bringing us from start to finish!