The MIT ROV Team

presents

Tim the Sixth

Built by the MIT ROV Team
Massachusetts Institute of Technology
Cambridge, Massachusetts.

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Abstract

This year, the MIT ROV team designed our ROV, *Tim the Sixth*, not only to compete in the MATE competition, but also to be used afterwards for both didactic and practical purposes, a goal we have been working towards for the last two years. The emphasis was on improvement of basic designs prototyped in the form of our 2005-06 ROV *MTHR* and our 2006-07 'bot *WiiBot1,* as well as making the ROV much more versatile, compatible different power systems, tethers, mission specific modules and sensors. These objectives, along with the size and maneuverability constraints we had set ourselves led us to design and build a compact, streamlined ROV, with small, powerful thrusters with highly efficient propellers, capable of using on-board batteries as well as tether supplied power and fiber-optic data lines as well as standard Cat 5/5e cables. Our mission modules include a gripper system designed from scratch and a temperature probe from our 2004-05 vehicle. Overall, this ROV can not only complete the MATE competition in a successful manner, but will also provide a good platform for future development.

The 2007-08 design cycle provided the team with many invaluable experiences. From getting dirty in the machine shop to attending black-tie receptions at the MIT museum to talk about the continuing MIT involvement with the sea and teaching school children about the role of ROVs in the energy sector, it has been an incredible year of pushing the envelope all round.

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Design Rationale

In the past two years, the primary goal of the MIT ROV Team has been to produce a modular, extensible robot with components that could be upgraded individually. The driving force behind this was to enable the vehicle to be reused multiple times with varying mission profiles. While the team saw some success in this endeavor, we realized that the designs of some of our main systems needed drastic improvements if they were to work in this fashion. The critical areas identified for improvement were the frame, which needed to be more robust and streamlined to increase vehicle survivability and efficiency and the propulsion system, to prevent leaks and breakdowns. It was also decided that the thrusters needed to be smaller in size to make the ROV more compact.

Changes were also made to the electrical system to accommodate the use of a power tether instead of on-board batteries and to the electronics to support a greater number of actuators and sensors. The topside control system saw a move to the JAVA programming environment from the existing Apple Cocoa suite to improve multi-platform usability. In addition, the team needed to design a new gripper system capable of handling the 0.907 kg dive weights used to simulate lava in missions 1 and 2.

Structural Frame

It was decided that it would be best for the team if we stuck with the same basic quadrilateral shape that we have used for the past few years. The basic skeleton can be seen in Figure 1. This basic shape has many advantages. As you can see, the top is wider than the bottom, which increases stability by reducing the center of mass/center of buoyancy moment arm. The box which houses the batteries sits on the bottom so that the center of mass remains low. As is, flat surfaces are multitude. However, this is not a hydro-dynamically efficient design. It is very bluff and has a huge coefficient of drag. Because of this, we determined that it was necessary to develop something to streamline the body. We considered foam fairings, a thermoformed hull, and the combination of the two, but in the end settled on foam fairings alone, since this would also solve the problem of flotation required.

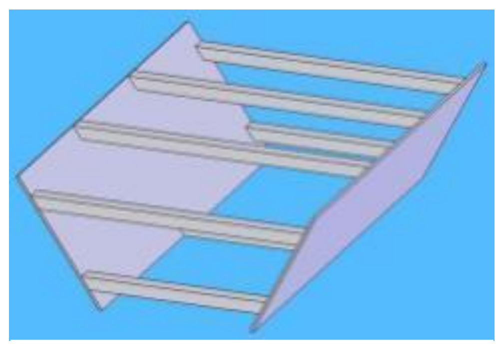

Fig 1: Original frame structure.

We designed the foam fairings with two goals in mind: (1) reduce drag and (2) avoid flow separation. By intuition, we know that so called “streamlined” shapes that cut through the water are more hydrodynamic than blocky flat surfaces. Flat surfaces stop all flow at the face, while rounded surfaces allow flow to continue past it. This results in piercing surfaces having a lower drag coefficient.

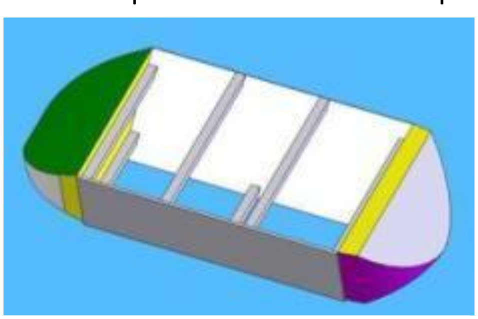

Fig 2: Frame solid model

We decided to shape a foam fairing to turn the flat frame surface into a more hydrodynamic conical-ellipsoid shape. Due to the trapezoidal face of the frame, we could design neither a purely elliptical nor a purely conical protrusion. The important characteristics are smoothness and angling to a point, which we achieved by various extrusion features in SolidWorks. We also decided also to angle to mid-height (symmetrically) to avoid unbalanced lift forces. Figure 2 shows the solid model for the finished frame and fairings, while Figure 3 shows the completed frame prior to wet testing. Figure 4 shows the results of hydrodynamic drag tests on the frame with and without foam fairings. For a complete description of the development process of the frame, please visit the online project repository at http://web.mit.edu/pricer/www/2.016%20Website%20webpagefile.htm .

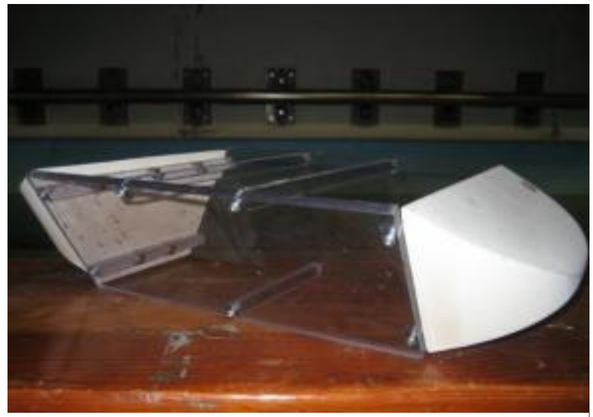

Fig 3: Completed structural frame

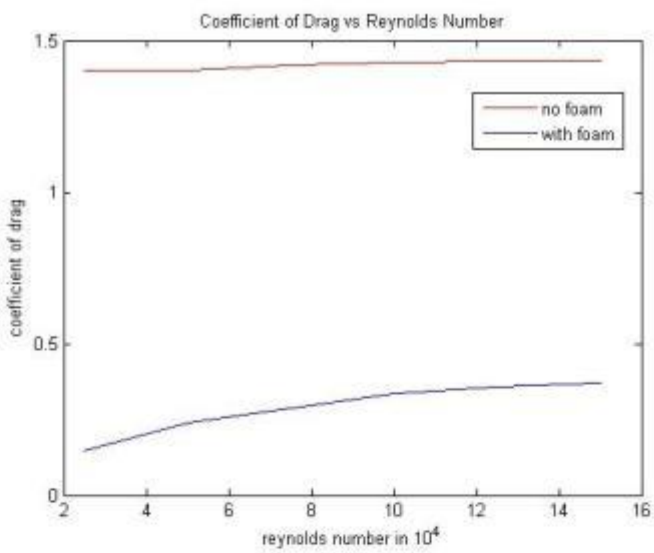

Fig 4: Hydrodynamic drag test results

Propulsion System

While reducing the size of the entire vehicle has been a strong design goal in each iteration of the MIT ROV Team vehicle, the thrusters from previous years were fairly large and consisted most of the vehicle's volume and weight. Reducing the size and weight of the thrusters would allow for increased agility due to lower inertial and added mass.

Furthermore, thrusters have historically been the most problematic subsystem. Creating a reliable seal around a rotating shaft is a difficult challenge, and elaborate shaft seals have not proven dependable. For the speeds that the propellers will be running at, using dynamic o-ring seals is a very feasible method for sealing rotating shafts, though their dependability is directly related to machining tolerances.

These concerns provided us with our two major objectives for the new propulsion system: decreased size and increased reliability. For purposes of clarity, we will refer to the motor, its housing and associated shafts (ie, all parts of the propulsor except the propeller) as the thruster.

Motor Selection

This year we wanted to use a smaller thruster than we had used in previous years. Previous thrusters used a Maxon RE 40 brushed DC motor that was 40 mm in diameter. This year, we chose a smaller Maxon RE 30 brushed DC motor with only 30 mm diameter, as shown in orange in Figure 2.[1] The Maxon RE 30 also operates on 12 V because that would be our system voltage if we chose to use an onboard power system.

Thruster

This year's thruster is shown in Figure 5. It is very compact and slender, with an outer diameter of only 1.4 inches and a length of 8.6 inches. It is designed with a minimal number of parts to help make assembly easier, and utilizes several redundant o-rings for both dynamic and static sealing. The shaft is supported on the outside with a graphalloy self-lubricating bearing. The power cable for the thruster is potted into the nose cap.

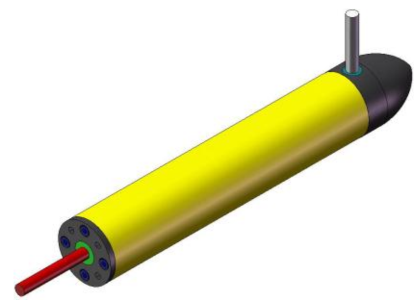

Fig 5: Thruster solid model

Housing: The housing is made of 6061 aluminum, and designed to be as low profile as possible, as shown in yellow in Figure 5. This helps not only with size but with heat dissipation as well, since a thin aluminum housing would conduct large amount of heat away from the motor, especially when submerged.

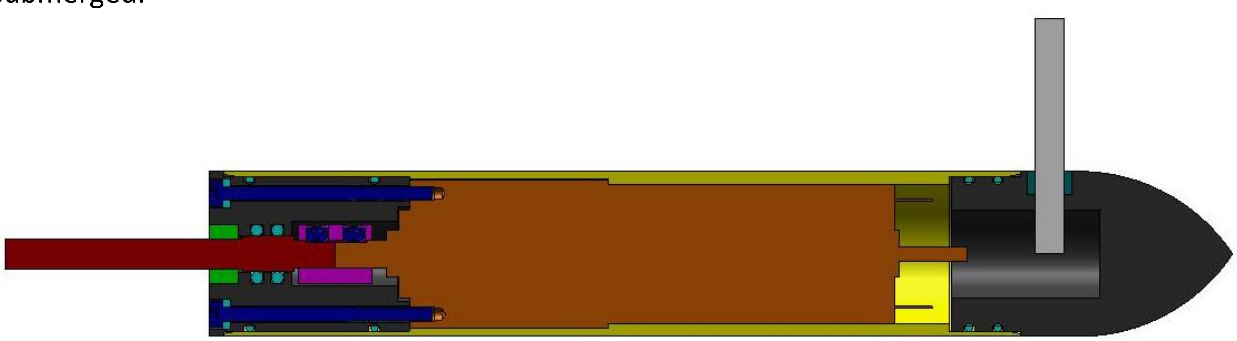

Fig 6: CAD model of thruster (section view)

[1] test.maxonmotor.com/docsx/Download/catalog 2005/Pdf/05 080 e.pdf [May 15, 2008]

Nose cap: The nose cap, shown in black in Figure 6 (to the right of the thruster) is made of black Delrin, a strong yet inexpensive plastic that offers high machinability. Two 2-025 viton o-rings were chosen to statically seal the nose cap with the housing due to their small size and appropriate diameter.

End cap: The end cap, shown as black in Figure 6 (left of thruster), is the most complicated piece that we needed to manufacture in the thruster. A complicated piece was chosen for simpler assembly purposes. The end cap is sealed with the same 2-025 viton o-rings that seal the nose cap. Four 45 mm M3 18-8 SS cap screws, only two of which are seen in Figure 4 hold the end cap onto the face of the motor. Fluorosilicone sealing washers sit underneath the heads of the cap screws to seal out water. These were chosen because it would be much simpler to install these small off-the-shelf washers than to machine a groove for a face-sealing o-ring between a multi-part end cap.

Fig 7: Partially assembled thruster, showing end cap

Shaft couplings: There were no readily available shaft couplings in the size and diameters required, so custom shaft couplings were designed, as shown in magenta in Figure 6. These were designed to be as small as possible yet highly functional. The shaft couplings are made of 1144 medium carbon steel. Steel was chosen over stainless steel because it was assumed the inside of the housing would be dry so rust would not be of concern and machining would be easier. If the housing flooded, the shaft coupling would be of very low concern. 1/8" #10-32 set screws tightly clamp onto the two stainless steel shafts while keeping a low profile.

Dynamic o-ring shaft seal: In previous years, the ROV team's thrusters typically used shaft seals. However, shaft seals were unreliable due to the rough college environments these thrusters are subject to. According to Parker O-Ring Handbook it was feasible to use o-rings at the speed we were running the shaft at. We consulted with industry professionals who also recommended o-rings for our purpose. Parker O-Ring Handbook recommends using the thinnest o-rings possible for better hit dissipation. However, since the o-rings sit in a female bore seal gland, special machining tools are required to make the inside-diameter cut. McMaster, our primary supplier, does not offer a cutting tool for the 2-0XX family of o-rings, only 2-1XX or greater, so we chose the 2-109 viton o-ring which had an inner diameter greater than our shaft diameter, required for proper assembly. This is an example of how manufacturing processes must be taken into account while performing even preliminary design work.

Bearings: The dynamic o-ring seal relies on concentricity and cannot tolerate significant radial deflections. Since the motor had contained one bearing for the shaft on the inside part of the housing, we needed a bearing on the outside of the o-rings to support the shaft from both ends. Ball bearing performance in a corrosive underwater environment is not typically very good, so we went with graphalloy self-lubricating bearings.[2] These sleeve bearings are touted by the manufacturer to have superior submerged performance, and were small enough to reasonably fit our design.

Shaft: The 316 stainless steel shaft, shown in red in Figure 4, also needed to be custom made due to a variety of diameters inside the end cap. The graphalloy bearing has an inner diameter of 0.250", while the Parker O-Ring Handbook required the sealing section to have a pistol diameter of 0.301". On the motor end, the output motor shaft diameter is 6 mm, so it was much easier to simply drill a through-hole for the shaft coupling and turn the thruster shaft down to 6 mm as well. The outer edge of the sealing section of the shaft is also chamfered to prevent damage to the o-rings during assembly. The material was chosen for the most corrosion resistance.

Thruster Placement: Two thrusters are mounted horizontally, extended from the body, providing thrust in the surge and yaw directions. Another two thrusters are mounted vertically but at an outward angle (hence the inverted trapezoid) to provide thrust in heave and sway directions.

<u>*Propellers*</u>

When designing the ROV's propulsion system, the team wanted to keep with the small compact design of the frame while still having the power to complete the tasks. These two considerations place the following constraints on the design process. The propulsion system would have to provide enough thrust so that the ROV would be able to return to the surface while carrying three of the 0.907 kg dive weights. Second, each propeller and duct should be less than 90% of the vehicle's overall width of 15.2cm to limit the additional drag in the vertical direction and to keep the ROV compact. Last, to minimize power consumption the propellers will need to be as efficient as possible while meeting the other design constraints.

To ensure that the size specifications were met in the design process, motors and gear heads were chosen that were relatively small yet would still provide an adequate speed and torque. 30cm diameter brushed motors coupled with a 14:1 gear head were chosen. This combination yielded a nominal output speed of 545rpm and a nominal torque of 724Nm. Of the possible combinations, this set up gave a speed and thrust that would be sufficient for the range of propellers to be considered.

To design the propellers a MATLAB™-based program at developed at MIT called OpenProp was implemented. OpenProp is an open-source propeller design program. It utilizes a 3D vortex lifting-line analysis to design light to moderately loaded propellers based on a user's inputs.[3] OpenProp is able to perform a parametric analysis (Figure 8) for initial optimizations and a single propeller design. In it's current state OpenProp has been proven to be a useful

[2] http://www.graphalloy.com/ [May 15, 2008]

[3] D'Epagnier, Kathryn P.. "An Open Source Parametric Propeller Design Tool." Oceans 2007. 1-2.

design tool for designing propellers meant to be used in small to moderately sized ROV's and AUV's[4].

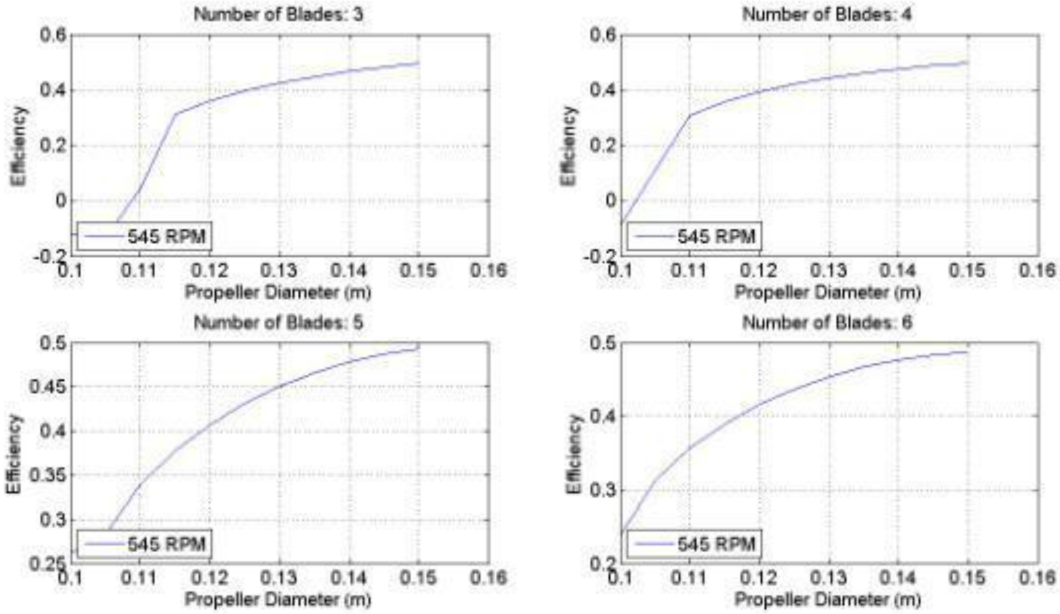

Fig 8: OpenProp parametric analysis output

At this point, the information gathered from the parametric analysis was used in OpenProp's single propeller design. The program was run several times using diameters between 12-13cm and outputs were compared to determine which size the final design would be. All other values were kept the same from the parametric analysis except that four blades were assumed.

During the single propeller design OpenProp outputs a Rhino 3D command file containing the propeller geometry (Figure 9). For the final propeller design a modified version of OpenProp developed by Katheryn D'Epagnier was used which fixed some problems with the final geometry and incorporated the hub in the output file. In order to 3D print the design it was saved as a .STL file (Figure 10).

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[4] D'Epagnier, Kathryn P.. "A Computational Tool for the Rapid Design and Prototyping of Propellers for Underwater Vehicles" (ME thesis, Massachusetts Institute of Technology, and Woods Hole Oceanographic Institution 2007), 3, 54-55.

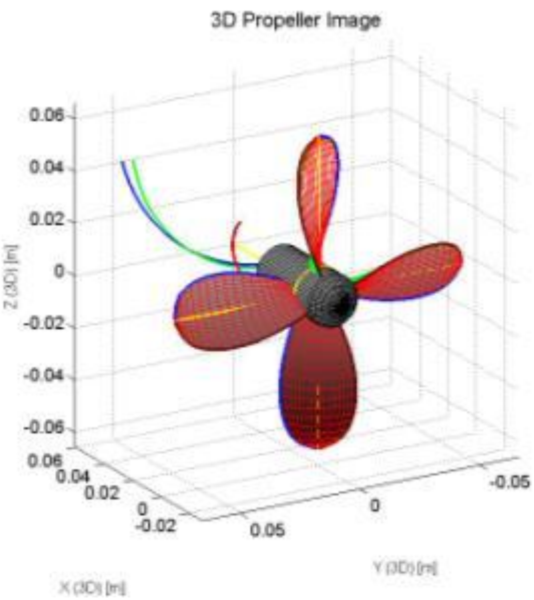

Fig 9: OpenProp geometry output

Fig 10: Final STL model of the propeller

Bottomside Power, Control and Sensor System

The schematic representation of the control system is shown in Figure 11. The central part of the control system is the Microchip PIC18F4431 microcontroller, which communicates with the topside computer and actuates the thrusters and servos on the ROV. The microcontroller receives commands from the surface by a serial RS-232 connection. A Texas

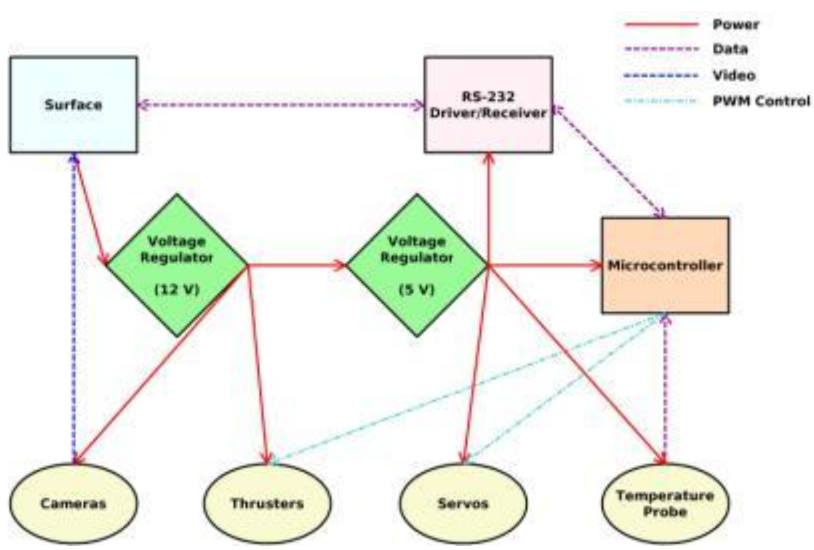

Fig 11: Schematic representation of bottomside control system

Instruments SN75C1406 chip is used to convert between the RS-232 voltage levels used by the topside computer and the TTL voltage levels used by the microcontroller. The control of the actuators is done through PWM signals that control both the thrusters and the servos. For the thrusters an STMicroelectronics VNH2SP30-E H-bridge is used to amplify the PWM control signal generated by the microcontroller to the current level needed for thruster operation. Figure 13 shows the detailed schematics for the bottomside control board.

Power: The two on-board voltage regulators provide a stable source of both 12V and 5V with a wide range of input voltages from the surface. The 12V source is based on a National Semiconductor LM5030 switching regulator, that can handle the large currents necessary to run the thrusters. It can be operated either with a topside source through a tether, or with on-board battery supplies. The 5V source is provided by an STMicroelectronics LD1084V50 linear regulator, which supplies only the microcontroller and the servos, so it has a fairly low current requirement. Figure 12 shows the electrical schematic for the vehicle.

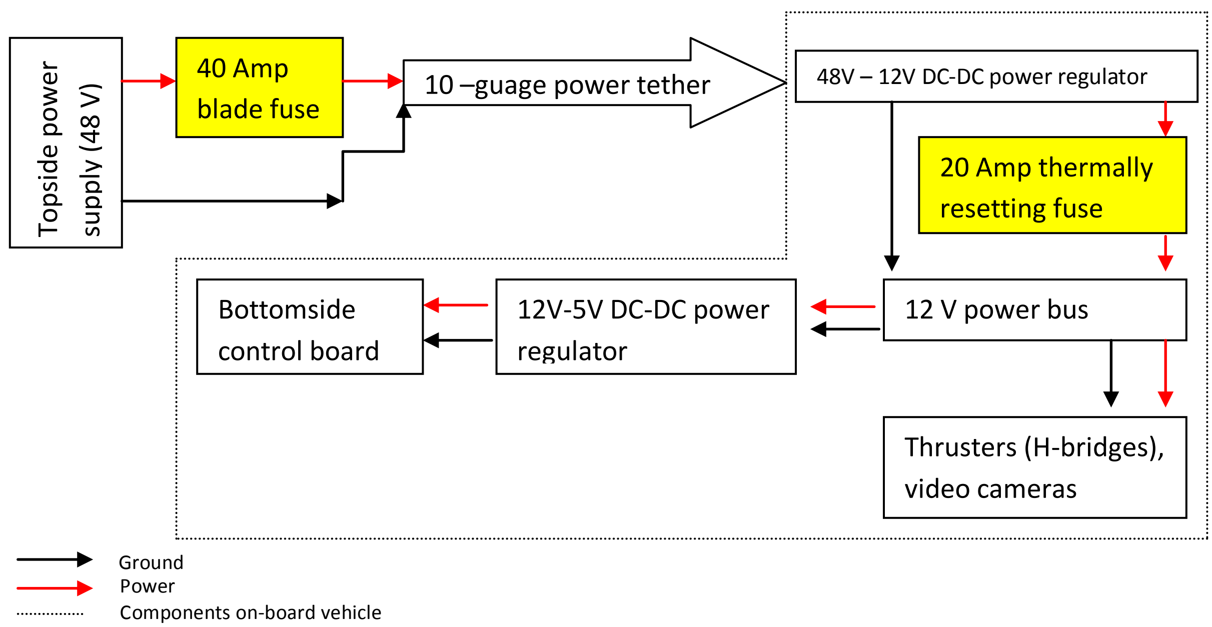

Fig 12: Electrical Schematic

Temperature sensors: The temperature sensing is performed by using a thermistor probe, which changes it's resistance based on temperature. A high precision resistor voltage divider and an Analog Devices AD622AR instrumentation amplifier are used to convert the resistance change to an analog voltage signal which is read by the microcontroller's analog to digital converter.

Video: In the current design the video signals from all four cameras are send directly to the surface through the tether. For compatibility with our fiber optic tether that only has two video channels, a video switching system is maintained in the control electronics, that allows any two of the four cameras to be send through the tether.

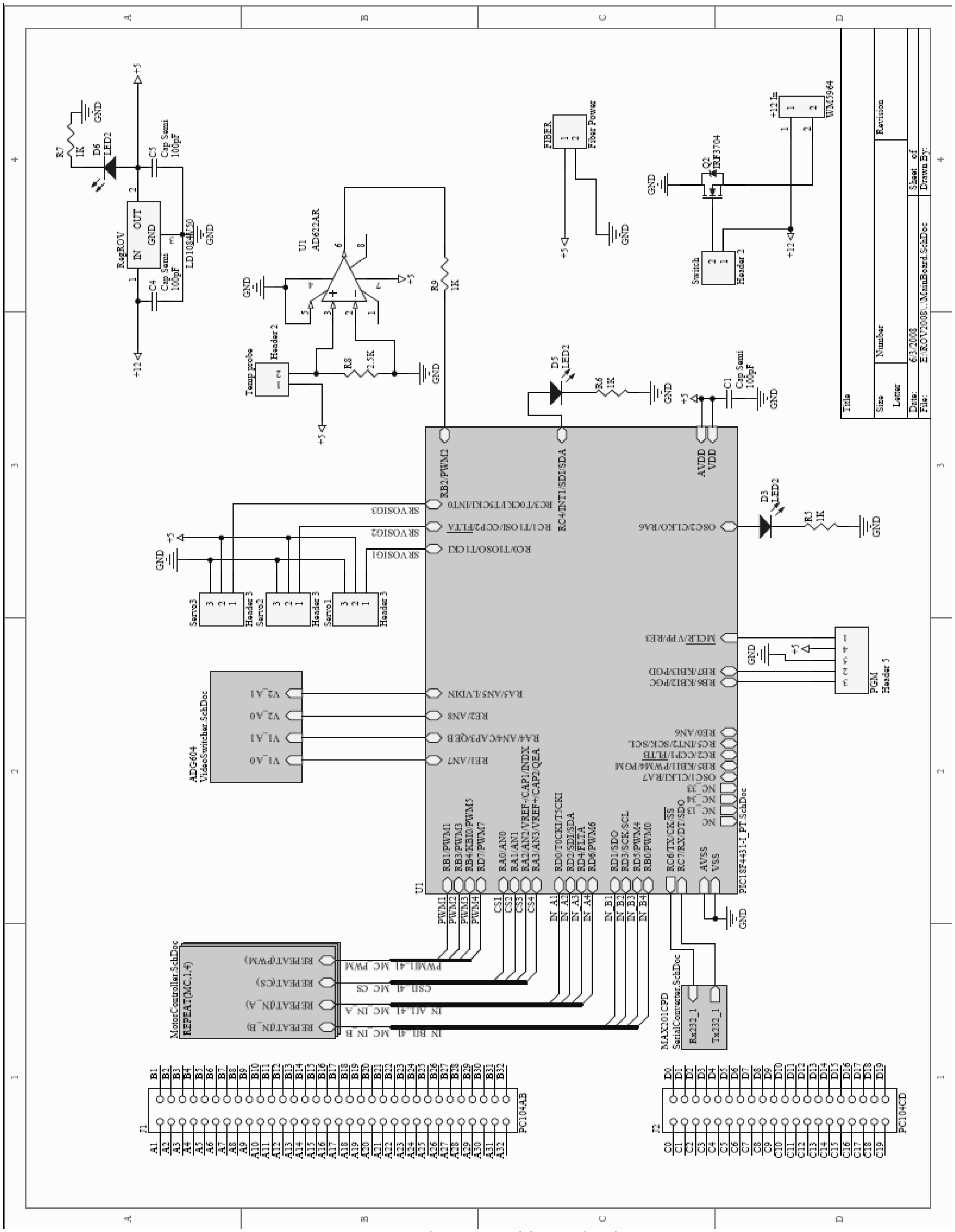

Fig 13: Bottomside control board schematics

Topside Control System

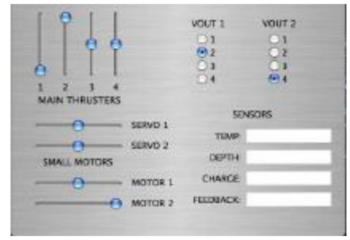

Fig 14: Screenshot of topside controls

Topside controls are driven by a custom JAVA application on a Windows laptop (See Figure 14). Algorithms for this application were taken directly from kROV 5.0, the team's previous topside software version (developed by K. Stiehl). The user provides input via joystick and buttons, which the application then maps to propulsor duty cycles and sends to the bottomside controller. Sensitivity settings can be changed by the user so that each pilot is able to customize the feel of the control to their own liking. It also has control for auxiliary motors and servos, along with calibration and display of sensors for depth, temperature, battery charge, and motor feedback. If a joystick is unavailable, the user can fly *MTHR* using the keyboard.

This application was developed to be portable and extensible. It can handle two ROVs at once if the user desires, driving each from a separate joystick.

JAVA usb drivers were authored by independent developer George Rhoten and are open source.[5] The drivers and the application can be used on linux and Windows platforms.

Gripper Arm

One of the most important requirements for this year's ROV is to be able to manipulate and retrieve three 0.907 kg dive weights. In order to fulfill this requirement, our ROV is equipped with a rail mounted grabber arm that consists of three unique components, the linear rail subsystem, grabber subsystem and variable cargo hold (Figure 15).

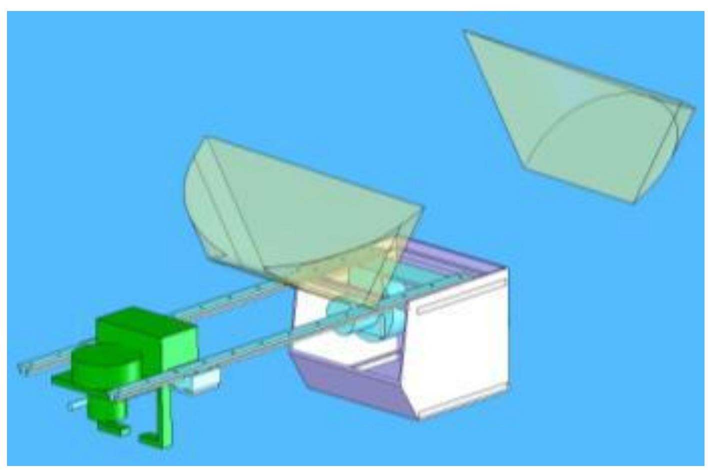

Fig 15: Gripper subsystems (Light blue- Linear Rail subsystem; Green- Grabber subsystem; Lavender- Variable Cargo Hold)

Linear Rail Subsystem: In order to facilitate a means of reliably transporting the 0.907 kg dive weights from its resting place to the netting, the gabber subsystem is mounted on a set of linear rails. There are several advantages of using a rail system, including reliability and persistence since the linear rails are relatively simple and supports a large amount of weight. Furthermore, the motor driven rails also provides a weight advantage against bulky hydraulic systems since the lead screw drive assembly powering the rail is also able to efficiently transfer the work done by the motor directly to moving the grabber from extended to retracted.

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[5] http://sourceforge.net/projects/javajoystick/ [May 31, 2008]

Some key features includes, having two rails to maximize structural robustness. The lead screw mechanism gives precision control and plenty of torque. Moreover, the lead screw drive system is also mounted off-center so it is out of the way of the grabber arm. V

Variable Cargo Hold: The final part is the variable cargo hold, which is mounted on the mid-section of the ROV. The cargo hold itself is made up of netting supported by some lightweight PVC. Its main purpose is to store up to three lead weights that the grabber deposited in it. During normal operation, it is designed to minimize interference with the ROV's performance by being collapsible and also mounted in the middle of the ROV to maintain balance. Additionally, the netting also significantly reduces water drag, leaving the speed unaffected.

Tether

There are two kinds of tethers our vehicle is designed to use. If powered by on-board batteries, we prefer to use a single strand of fiber optic cable for purposes of manoeuverbility. It passively spools out of a disposable 500 meter long coil. If the tether becomes tangled during a mission, it can simply be cut and re-terminated for the next use. Signals are encoded and decoded by MiniMux2 boards, donated by Prizm Advanced Communication Electronics Inc. This setup provides *MTHR* with 2 video channels, 2 RS-232 serial channels, and one RS-485 serial channel. The tiny tether has negligible drag and weight, so it does not change vehicle dynamics, but care must be taken to avoid tangling or pinching the fiber so that communication is not interrupted or destroyed.

The second kind of tether provides power as well as data transmission capability to the vehicle and will be used for the MATE International ROV Competition. It consists of two insulated 10 guage wires for power transmission and a standard Cat 5 cable for data transmission. 5 lines on the Cat 5 are used for video transmission, two are used to transmit serial data to and from the topside controller and the last line is reserved for emergency use in case of breakages. The cables are housed in a water-resistant sheath and the tether has a usable length of 30.

Description of a Challenge

Our decision to redesign our propellers presented many difficulties. The first problem was learning how to use the OpenProp software. The team members who had designed our first set of custom propellers had all graduated, and the current members did not have the same level of expertise in marine screw design. In addition, the software available to the team two years ago was no longer accessible. OpenProp was a brand new code and even the team's mentors were not very familiar with it.

With continued hard work and debugging, our propeller design team was able to get the OpenProp code to work for our purposes. By this time, we had also acquired propeller design know-how by consulting relevant texts and speaking to experts in the area. Armed with these successes, we set out to produce our first designs, which turned out to be extremely satisfactory.

We then set out to try and prototype the propellers. This was when we hit our second roadblock. We had originally planned to mill out the propellers from solid plastic blocks, but learned from our mentors that this process led to the blades becoming ridged thus reducing the efficiency of the thrusters. Fortunately, we avoided this problem with our machine shop at the Edgerton Center at MIT purchasing a 3D printer. We could now print these props exactly as they had been designed.

This is where we hit our third problem. The 3D printer did not accept the Rhino file output from OpenProp and needed instead a .stl file. After much research, we realized that the best way to do the conversion was to first turn the Rhino outputs into a standard geometry file with Cartesian locations of points on the blade surface, and then convert it to the required stl file format. We did the former by using software from the Ocean Engineering Teaching Lab at MIT and then wrote a MATLAB script to do the latter. Thus we were able to print our propellers.

Troubleshooting Technique

As in any technical endeavor, many of our systems do not work the first time they are plugged into the vehicle. This is especially true if individual subsystems and components have not been tested along the way. One of the more frustrating malfunctions to have while piloting an ROV is to have your video feeds fail. This happened to us on our first test run at the MIT Tow Tank. Three out of four video cameras suddenly stopped transmitting.

In order to troubleshoot this problem, we looked at the video system in parts. We first checked to see that all inputs were correctly plugged in. Having established that this was so, we checked out connectivity across our Cat 5 data tether by checking each of the 8 wires for breaks using a multi-meter. The problem did not lie here either.

The next step was to disconnect the waterproof connectors for the cameras and ensure that each power output pin was indeed supplying the required 12 volts. We could not establish this by looking at the cameras since the ones we were using that day did not have illumination LEDs. This is where we discovered that three cameras were not receiving power at all. This necessitated opening the bottomside control box to check for the cause. It was easy to spot the fault once we did open the box up. It seems that power supply wires to these three cameras were soldered together and then not soldered very well to the power outlet port on the power bus. This bad soldering joint had failed. We fixed it and were up and running again.

Had we not systematically gone about checking each point in the system, we would have spent a significantly greater amount of time trying to troubleshoot our problem. Breaking down large systems into parts and checking each node along a pathway is a time saving technique that we employed throughout the year to ensure a working vehicle.

Lesson Learned

by Grace Kane

After joining the team, two other freshmen and I were given the task of designing the robot arm, an experience which taught each one of us several valuable lessons. Designing something tailored to a specific task was a new and difficult challenge. I learned that there are a lot more aspects to consider than you would first think when initially brainstorming the idea – the materials available, the expense and how to integrate the system with the rest of the vehicle. We had to consider how to fit the arm in the vehicle and how components of the ROV might help or hinder the design.

I think the most important lesson we learned while building our ROV was to always start early. In designing the arm we put off developing certain parts of the design far later than we should have. When we finally started, we discovered that the task was not as easy as we had expected it to be and so ended up doing a lot of work at the last moment.

This ties into another lesson we learned, that is, designs should be kept as simple as possible, because more complicated designs may turn out to be unreliable and cause more problems in themselves. I also learned that nothing within a design should be assumed – things don't always work as planned and it is a lot easier to check the feasibility of all parts of a design initially, than to go back and drastically change components when the system doesn't work in testing.

We also learned some technical skills from the experience – I learned how to select and size actuators depending on the task at hand and we were taught how to use SolidWorks in a workshop run by the senior members.

In all, in think all the freshmen learned and gained a lot from the experience of being on the MIT ROV Team. I hope to stay involved in what is a fun, interesting and challenging project.

Future Improvements

Our plans for the future are not much different this year than they were over the last two years. The basically reflect those portions of our standing objectives that we have not yet been able to achieve.

Inertial Guidance

One of our objectives is to be able to use ROVs of our design for monitoring the environment in small rivers. These are often murky, rendering cameras nearly useless. In order to operate in such environments, we would like to implement a cheap but accurate inertial guidance system, including COTS MEMS accelerometers and gyroscopes, in addition to depth sensors.

Autonomous Operation

Since the payload includes two PC-104 boards, there is a possibility that our vehicle could be used in an autonomous or semi-autonomous mode, similar to WHOI's new HROV. *Tim VI* would be an ideal platform for testing new autonomous control systems, since it has a simple serial interface to drive the motors directly. This autonomous operation payload would have to include all the necessary navigational instruments (electronic compass, gyros, accelerometers, etc.) on the two boards, along with all the required computing power.

Pilot Training

Our team hopes to develop a pilot training program to improve our team members' capabilities in driving our vehicles. An ROV can be the most advanced piece of equipment on a boat, but if the pilot is not proficient, the mission will suffer. Since we focused on making generally capable ROVs, we hope to have team members practice flying it during the term as we are developing the additions for next year, instead of dismantling it at the beginning of the term.

Exploration of Deep Sea Hydrothermal Vent Systems

It is in the nature of research on deep sea hydrothermal vents to require robot assistance. As such, John R. Delaney has used all manners of underwater robots, including remotely operated and autonomous underwater vehicles, in his research on mid-oceanic ridges.

A marine geologist at the University of Washington, Delaney started out with an interest in volcanism that gradually went underwater. By chance, he wrote his thesis on volatile gases in seafloor basalt. But he was first truly inspired to research the ocean floor late in 1980, when he took a trip in the submersible *Alvin*. From that dive forward, he has worked extensively on understanding many aspects of the Juan de Fuca Plate in the nearby Pacific Ocean[6].

Researching the mid-ocean ridge takes many things into account, and John Delaney takes a multidisciplinary approach that goes beyond the geology. For example, his interest in black smoker chimneys used mineralogy and chemistry to examine the environment in which microbes were likely to reside. Among other things, he helped organize the RIDGE 2000

[6] Malakoff, David. "John Delaney Profile: Marine Geologist Hopes to Hear the Heartbeat of the Planet." *Science*. 303.5659 (2004): 751-752.

program, an interdisciplinary approach to studying the mid-ocean ridges, including hydrothermal vents and the volcanic crust, sponsored by the National Science Foundation[7].

He has looked at deep sea hydrothermal vents all over the world, in both the Pacific and the Atlantic Oceans, and used multiple ROVs to do so. His most well known expedition to the Pacific in 1998 to retrieve several black smokers for examination was documented by the NOVA television program. In this expedition, Delaney had use of the ROV ROPOS, used to study and retrieve samples of the smokers and record much of the undersea footage that was shown on the show[8].

Delaney's latest project is NEPTUNE – the North-East Pacific Time-series Undersea Networked Experiments[9]. The aim of NEPTUNE is to establish a permanent ocean observatory in the northeast Pacific, right off the coast of the states of Washington and Oregon and part of British Columbia. It is essentially, a "system of high-speed fiber-optic submarine cables linking a series of seafloor nodes supporting thousands of assorted measuring instruments, video equipment, and robotic vehicles that could upload power and download data at undersea docks"[10]. All this is in attempt to understand more fully the ocean dynamics that affect everything from the weather to the submarine food chain. Delaney even envisions the seafloor as the perfect testbed to simulate the extreme environments found on other planetary bodies.

Reflections on the Experience

Apart from all the engineering challenges and activities that the MIT ROV Team undertakes, perhaps our most rewarding experiences occur as we try to fulfill our social goals – teaching children and adults alike about the importance of underwater resources, both living and otherwise, and the critical role of ROVs in the exploration and protection of these resources.

In September 2007, the team began a new partnership with the MIT Museum to aid in these efforts. The first step was the induction of the 2006-07 WiiBot1 into the museum's new maritime archive. The reception for this event was extremely well attended by professionals and college students, and it was very heartening to see the interest that people expressed in the oceanic environment and student involvement in its exploration after speaking to team members in attendance. We made several contacts with students from other departments, all

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[7] *Ridge 2000 Program*. 29 May 2008. The Ridge 2000 Program at the Scripps Institute of Oceanography. 25 May 2008 [http://www.ridge2000.org/index.php]
[8] *Into the Abyss*. Oct 2000. NOVA Online for PBS by the WGBH Science Unit. 25 May 2008 [http://www.pbs.org/wgbh/nova/abyss/]
[9] *NEPTUNE*. 7 Dec 2007. The NEPTUNE Project and the University of Washington. 26 May 2008 [http://www.neptune.washington.edu/index.jsp]
[10] Delaney, John R. and Alan D. Chave. "NEPTUNE: A fiber-optic 'telescope' to inner space." *Oceanus*. 42.1 (2000): 10-11

of whom expressed the desire to work with the team either as technical collaborators or as partners in our educational efforts.

The next event we attended at the museum was on the 2nd of May, immediately after the New England regional, which we had attended in order to qualify for the International Competition. This event was part of the second Annual Cambridge Science Festival, and focused mainly on school children. The issue of the hour was energy. It felt great to talk about the involvement of ROVs in the development of our current sources of energy – the offshore oilfields in this case, as well as their potential involvement in sources of the future – for example offshore wind farms.

The day also provided us a chance to demonstrate the differences between our previous competition robot and the current one. It was a wonderful opportunity to pass along our enthusiasm for technological improvements to the kids, and we look forward to carrying on this tradition in the years to come.

Acknowledgements

All the members of the MIT ROV Team would like to thank our sponsors and advisors for their support, without which we would not be able to continue our hands-on education in marine robotics.

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MIT Center for Ocean Engineering
MIT Department of Mechanical Engineering
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The MATE Center
MIT Sea Grant College Program
Prizm Advanced Communication and Electronics
Altium
Fiber Instrument Sales, Inc
The Ocean Engineering Teaching Lab
The MIT Museum

Prof. Franz Hover
Jordan Stanway
Lauren Cooney
Dan Walker

Appendix A
MIT ROV Team Budget – FY2008

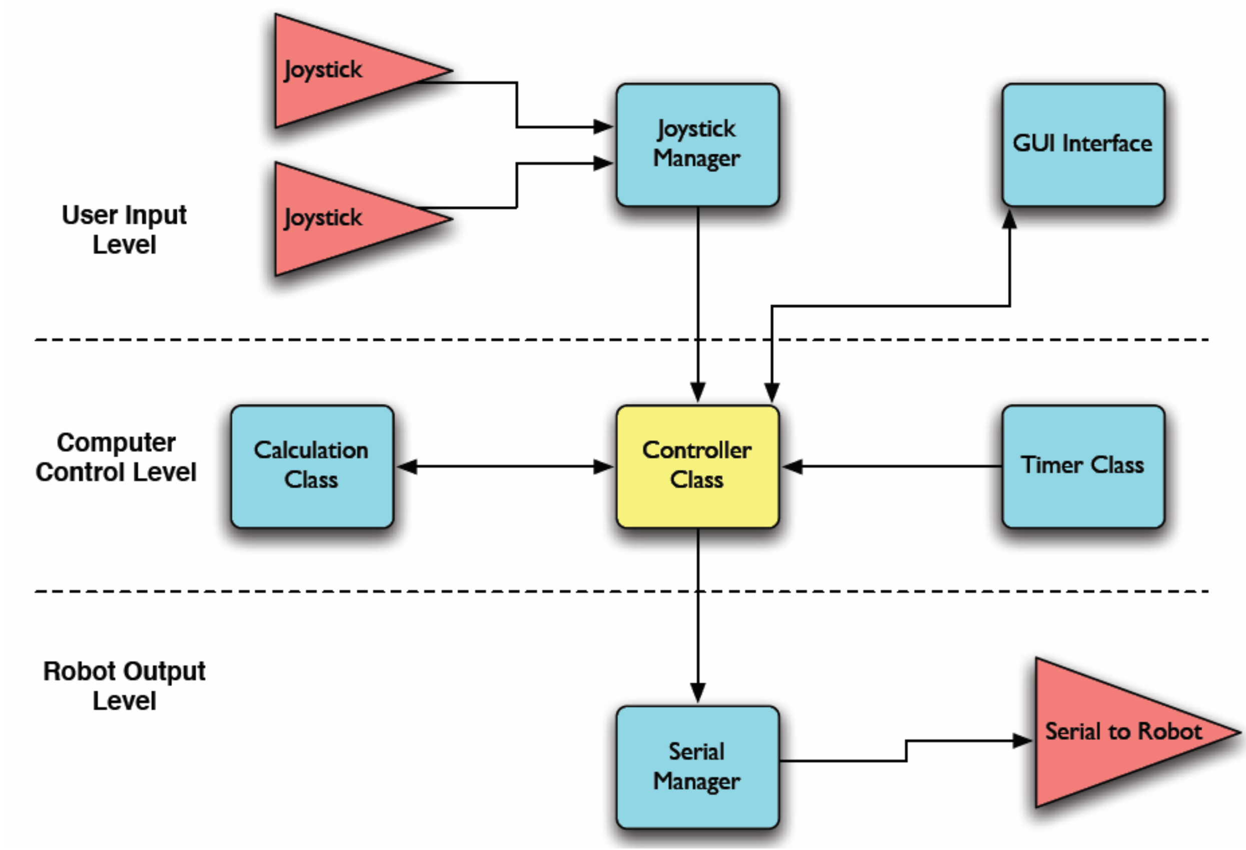
Team Expenses

ROV			
	Thrusters	4 x $537.50	$2,150.00
	Frame		$250.24
	Gripper		$180.00
	Tether		$100.00
	Electronics		$400.00
	Overhead		$450.00
Research			
	Hydrodynamic Frame		$300.00
	Thrusters		$500.00
	Propellers		$600.00
	Gripper		$150.00
Media			
	Poster		$150.00
	Paper		$50.00
	Resume book		$30.00
	T-shirts		$301.55
Travel			
	Rental car (Quals)		$54.78
	Hotel		$3,143.28
	Vans		$547.65
	Shipping		$400.00
	Airfare		$3,636.00
Food			$419.00
Capital			
	Computer		$627.94
	Tools		$250.00
Total outlay:			$14,690.44

Resources

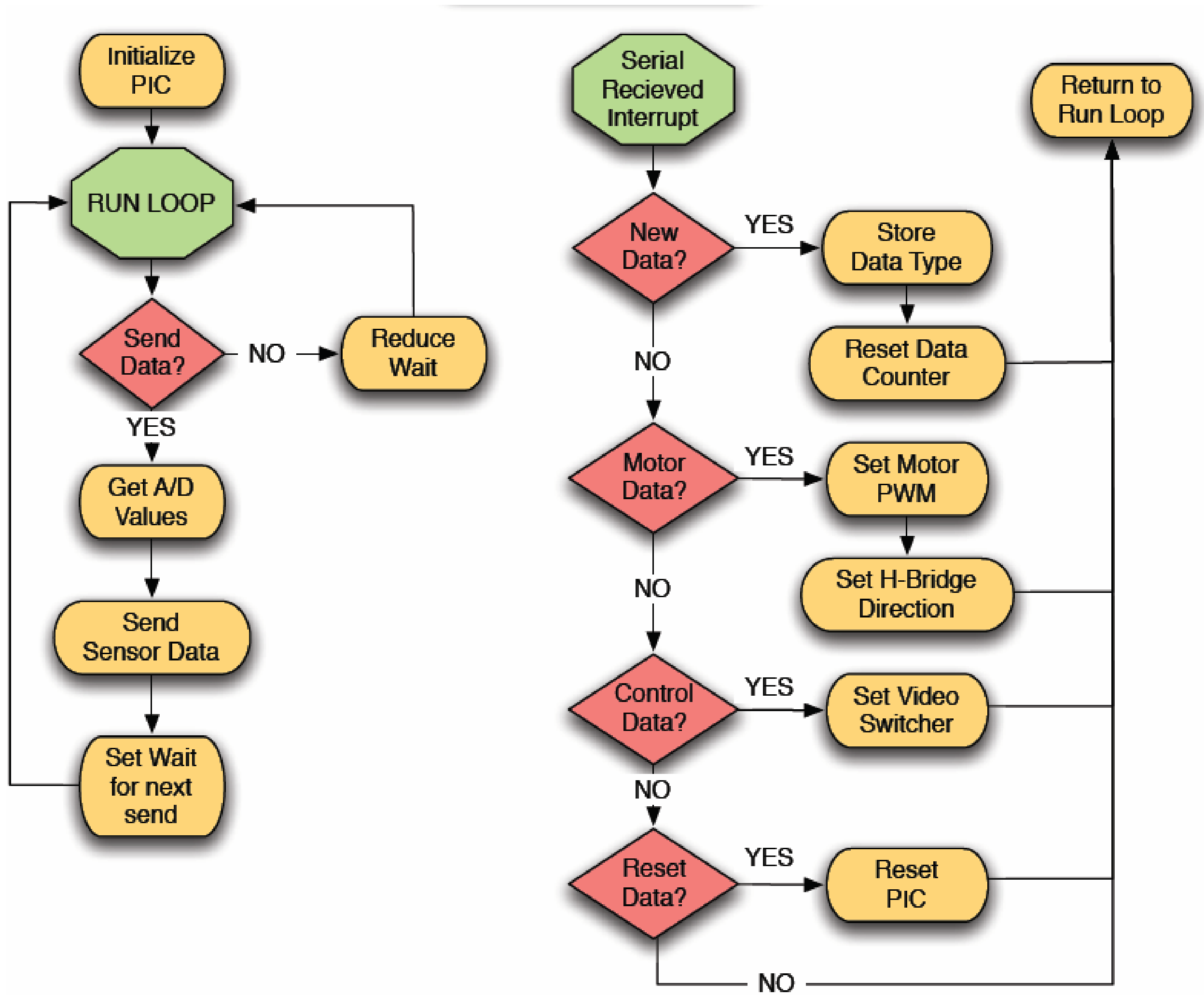
Monetary			
	Exxon Mobil contribution		$6,500
	Chevron contribution		$5,000
	MIT Mech. E contribution		$3,000
	MIT COE contribution		$3,000
	MIT Ocean Science and Engineering contribution		$3,000
Total monetary resources:			$20,500
Other			
	Altium	Circuit Maker	$12,000
Total donated items:			$12,000
Re-used items			
	Cameras		$800
	Power Tether		$53.30
Total re-used items			$853

Appendix B
Topside Control Flowchart[11]



[11] Based on control scheme design by Kurt Stiehl, MIT ROV Team 2006-07

Appendix C
Bottomside Control Flowchart[12]



[12] Based on control scheme design by Kurt Stiehl, MIT ROV Team 2006-07