

Senior Design Project Proposal

Autonomous Underwater Vehicle



Senior Design Group 29

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Abstract

The Association for Unmanned Vehicle Systems International (AUVSI) and the United States Office of Naval Research hosts a competition every year in pursuit of the advancement of AUV Technology. This year's competition will be the Sixth International Autonomous Underwater Vehicle (AUV) Competition (2003).The competition consists of construction of an AUV, which can perform simple navigation tasks involving homing onto a signal source, obstacle avoidance etc. and also mission specific tasks involving underwater object detection and identification, acoustic beacon frequency detection etc, when they are released in mid February 03.

Stevens Institute of Technology has been actively participating in the AUVSI competition since its commencement in 1998. This year the design and construction of the AUV will be undertaken as an interdisciplinary project, jointly by the Electrical and Computer Engineering (ECE) Department, the Mechanical Engineering (ME) Department and the Computer Science (CS) Department.

The AUV will be decomposed into subsystems and assigned to groups of students from all 3 departments. There will be a special system integration team who will undertake the task of integrating all the subsystems. This proposal details the plan to meet up with this challenge and complete the project in time to enter the AUVSI Competition.

Mission Statement and Past efforts

The basic mission objectives are for a self-propelled, autonomous vehicle to leave the starting point in the arena, pass through the validation gate, find the active object array through navigation, determine the shallowest depth of the object array, determine the characteristics of the object array, and recover a marker in the object array before the time runs out. Navigation is achieved through feedback from mission specific sensors determine after parameters are set. Points are awarded for accomplishing each part of the mission in any order after passing through the validation gate.

Stevens has been fairing decently in the past years in the AUVSI competition. The first AUV, the Poseidon, place second in 1998. The following year with the same hull and basic modifications the project got an honorable mention in the contest. In 2000, the AUV hull was redesigned and named the Triton. Even after having some faulty wiring and unprecedented hull breaches, the team was placed 8th. In 2001, the design team decided to use the same hull, and modify the subsystem designs. This was an uncalculated risk and can be said to be the primary reason for the teams last place finish. After looking at the past years designs, last years team decided to abandon going to the competition and come up with a basic AUV systems design that could be modified every year. This approach was commendable as it would give the teams in the future, an already functional system to start work on, instead of having them come up with a new system altogether.

The 2002 team also built a basic test bed, on which all the systems could be mounted and tested. The test bed was intended to be a temporary substitution for the hull, till the mechanical engineering students came up with a feasible hull design. This unfortunately never happened. Even though a hull design was drafted by the mechanical engineering team last year, it was far from complete, and could not be built. Yet, last years team saved us a great deal of work as we have a working test bed, on which to test new design ideas on.

Technical Challenges

The mechanical design of the hull is crucial to the success of the AUV. The most complicated and successful systems combined with well thought out algorithms will not accomplish much if certain things are not kept dry. This year the hull design is also being done by the ECE team. This will prove a tough challenge, but we have managed to secure the help of Davidson Laboratory, the marine engineering division of Stevens Institute of Technology. They will prove extremely valuable as their expertise is underwater ROV's and hull design.

The obstacle avoidance system for the AUV's autopilot is also going to be upgraded. This year we're going to be using a multi-beam scanning sonar to map obstacles for the AUV. Now, a sonar is a device designed with a man in the loop, ie.. a sonar gives us images of the ocean floor and based on these images the sonar operator presents his analysis of the objects/obstacles underwater. This process is to incorporate this analytical process into software which is a tough task.

As subcomponents feed information the computer systems controlling the AUV, an accurate navigation system is needed to ensure proper movement in the environment. Having such a navigation system will enable the sub to return to its original location, where just executing navigation commands in reverse would prove too inaccurate in the physical world. Being able to recount what happened where and what time improves the AUV's capabilities and facilitates the accomplishment of other requirements.

The AUV's computer system ties all components together and makes all decisions from data retrieved from sensors and navigation. A computer system must be powerful, expandable, flexible, physically tough, and small enough to fit inside the AUV. The algorithms that the computer must execute constantly must be stable and intelligent enough to handle all possible situations that may arise during the course of the competition runs.

Organization Chart

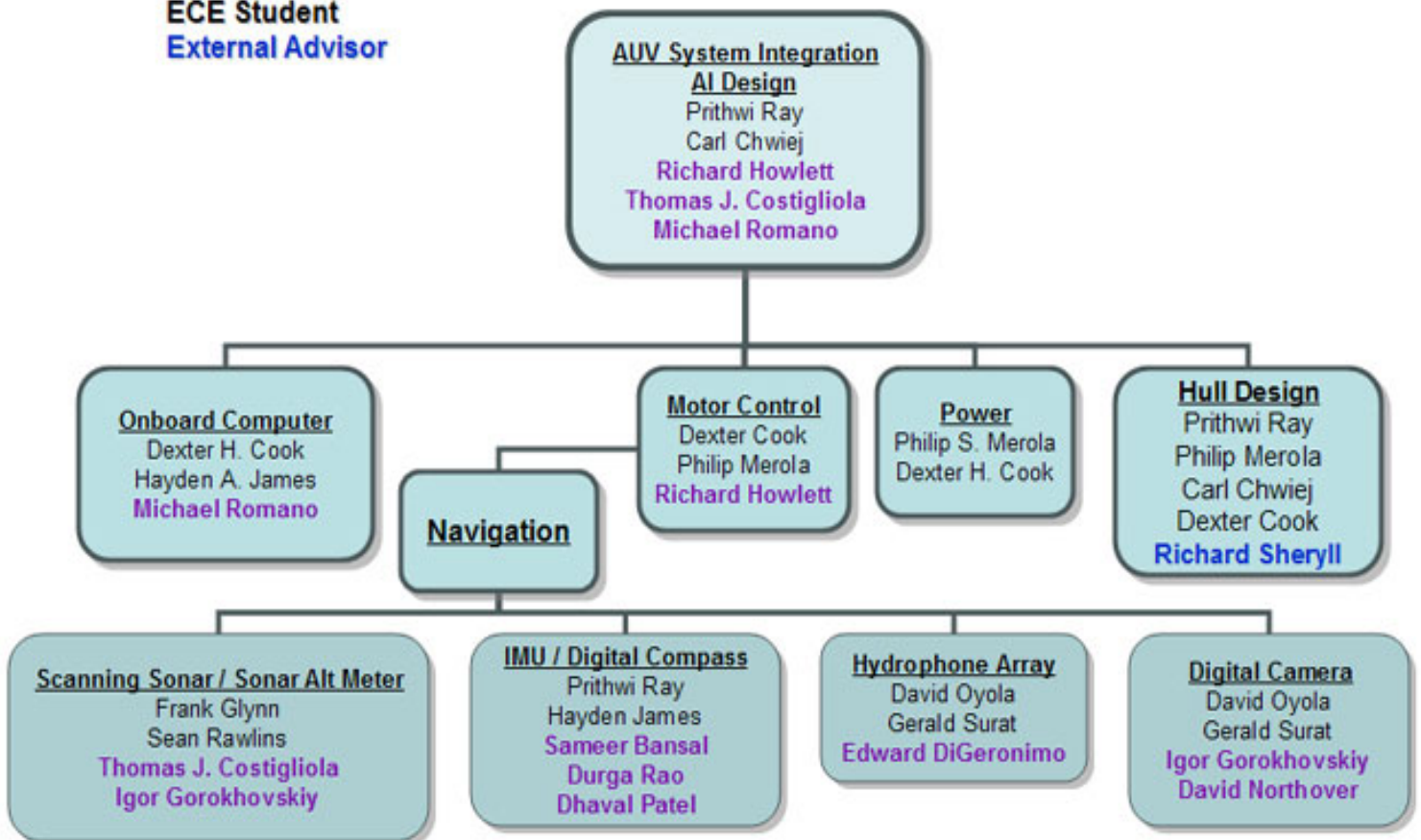
This year the AUV will be decomposed into subsystems and assigned to groups of students from ECE, CS, ME departments. There will be a special system integration team who will undertake the task of integrating all the subsystems.

Each subsystem team has have a Primary in charge, and a secondary/backup in charge. The following is the organization chart of the '03 AUV team.

Figure 1: Organization Chart

AUV Team Subsystem Assignments

CS Student
ECE Student
External Advisor



Navigation System Components

Pressure Transducer: indicate the depth of the AUV below the surface of the water body.

Sonar Altimeter: indicates the AUV's distance from the ocean floor.

Combined, these two devices will act an obstacle avoidance/navigation system for the AUV in the vertical axis of motion.

Digital Compass: indicates heading, pitch and roll of the AUV.

Inertial Measurement Unit (IMU): generates acceleration vectors with relation to the AUV's starting position. It also gives the pitch, yaw, and roll rates of the AUV.

The IMU along with the digital compass, the pressure transducer and the sonar altimeter, form the AUV's navigation backbone. Combined, these devices give the AUV an accurate idea of its position in 3 dimensions relative to the starting position.

Multi beam Scanning Sonar: scans the ocean floor for obstructions/objects and maps it for the AUV. It's the most expensive piece of hardware in the AUV, and will play a major part in the successful completion of the project.

The sonar is our primary obstacle avoidance system. Along with obstacle avoidance, it also helps in detection of underwater objects that might be a part of the mission. As mentioned before the major obstacle regarding the scanning sonar is that any sonar unit is designed with a man in the loop view. With the help of the CS team members, the data stream from the sonar has to be analyzed and interfaced with the navigation system software so that the process can be automated and the man in the loop can be removed.

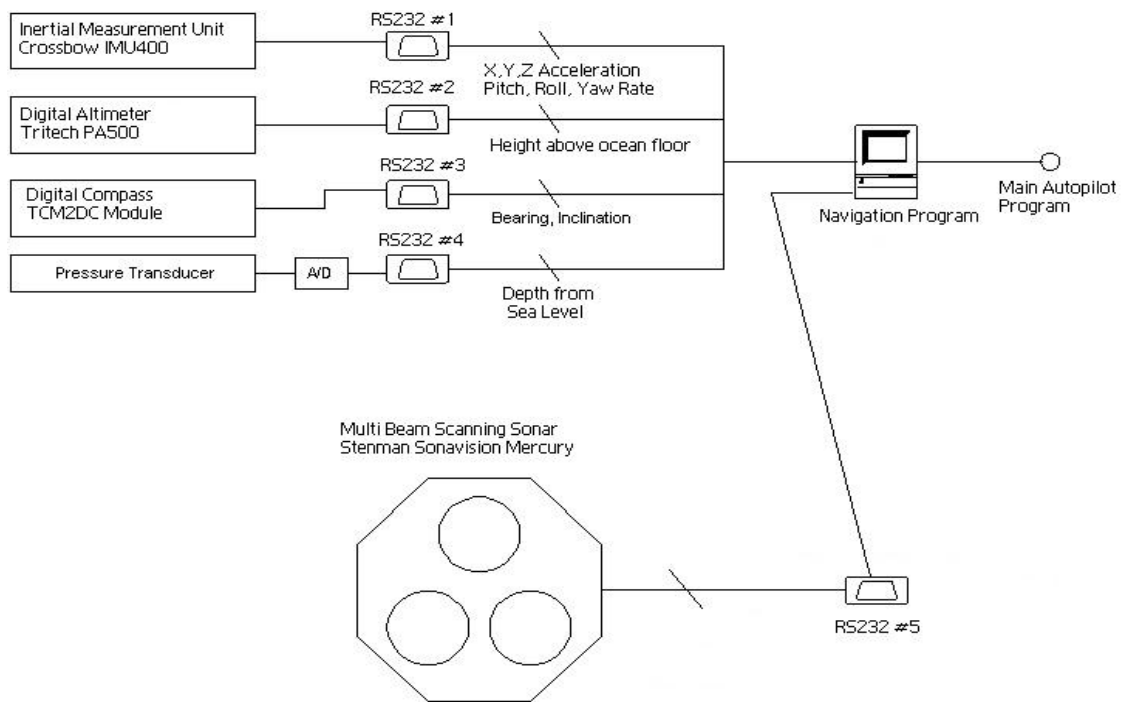
Digital Camera: unit gives a video feed to the AUV of the area in front of it. It produces an encoded video feed which is fed into a decoder card mounted on the onboard computer to generate still frames for the navigation system to process.

The digital camera uses an edge detection algorithm to detect underwater objects, and gates. It is also used to photograph any objects that are to be identified in the

competition. The digital camera also acts as our backup obstacle avoidance system, as based on its inputs, navigational decisions can be made.

Hydrophones: are essentially underwater microphones and are placed on various parts of the AUV. They listen for underwater sounds generated by acoustic beacons, and based on Time Difference of Arrival (TDOA) algorithm, give a direction to the acoustic beacon. For our design, we have 4 hydrophones mounted on the AUV. The location of the hydrophones on the hull is critical as this affects their ability to distinguish time delay between the receptions of a ping from an acoustic beacon, from one hydrophone to another.

Figure 2: Navigation System Components



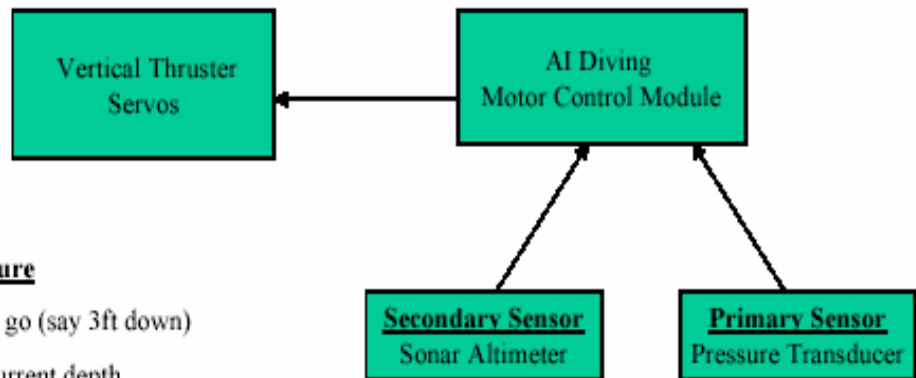
Basic Navigation Processes

Once an acoustic beacon is detected by the hydrophones, based on the time difference of reception between the various hydrophones the computer calculates the originating direction. Next the shortest vector to the beacon is calculated based on this information. As the AUV moves, the scanning sonar is used to detect obstructions in its path, and based on the sonar image, course corrections are made by the onboard computer.

In the case of an underwater gate, the digital camera is used to analyze the approach to the gate using an edge detection algorithm and the dimensions of the gate as a calculating factor. Then the required course corrections are made as the AUV approaches the gate in order to pass thro the gate successfully. Since we do not have the mission specific tasks until Jan-Feb, we will be developing basic navigation skills expected in all missions. Once the specs are released, the AUV will be modified to fit the specs.

The Navigation and Motor Control algorithm is described below.

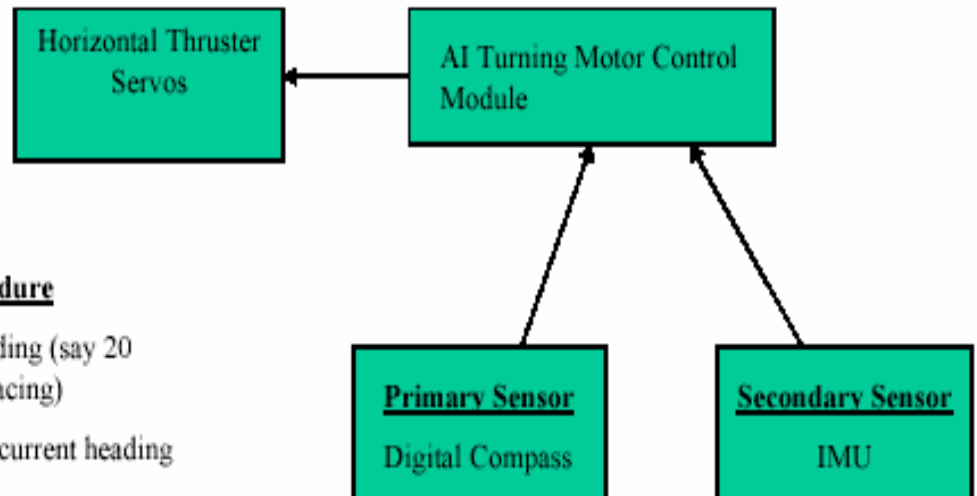
Z axis Motion



AI Motor Control Decision Procedure

1. AI gets input on how deep to go (say 3ft down)
2. Queries Primary Sensor for current depth
3. Queries Secondary sensor for floor depth
4. Calculates if diving to given depth is possible
5. **IF YES : Starts vertical thrusters in specified direction**
6. **Queries Primary Sensor for depth at constant intervals (to be determined by actual testing) and cross checks with input data to see if desired depth reached. GOTO STEP 8**
7. IF in step 4 the depth indicated is unreachable, then the AI sets input depth to 1ft above ocean floor, flags an error log and goes to step 6.
8. END

Turning Motion XY Plane



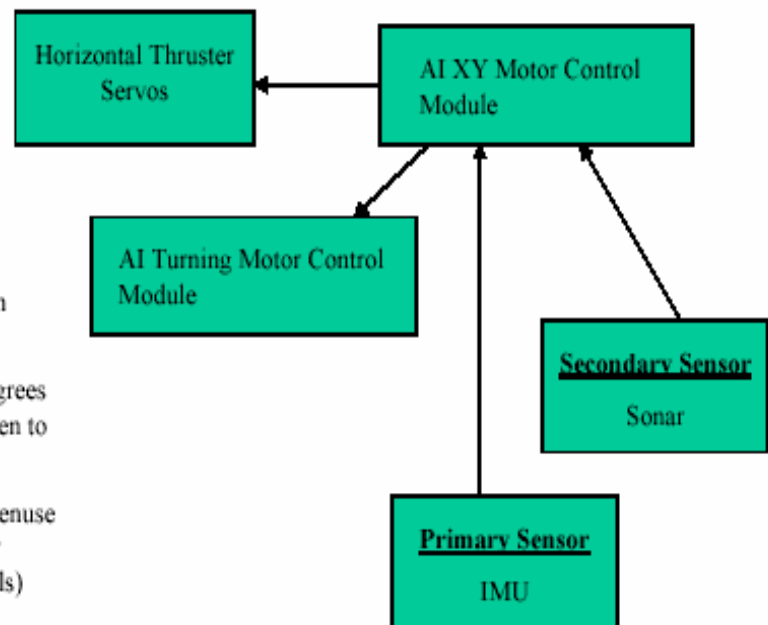
AI Motor Control Decision Procedure

1. AI gets input on which heading (say 20 degrees right from current facing)
2. Queries Primary Sensor for current heading
3. Queries Secondary sensor for current heading
4. Calculates AVG heading and sets it as starting point.
5. Starts one of the two Horizontal Thrusters depending on specified direction in order to turn, and reverses the other (optional)
6. Queries Primary Sensor for heading change at constant intervals (to be determined by actual testing). When required heading reached, turns off horizontal motors.
7. END

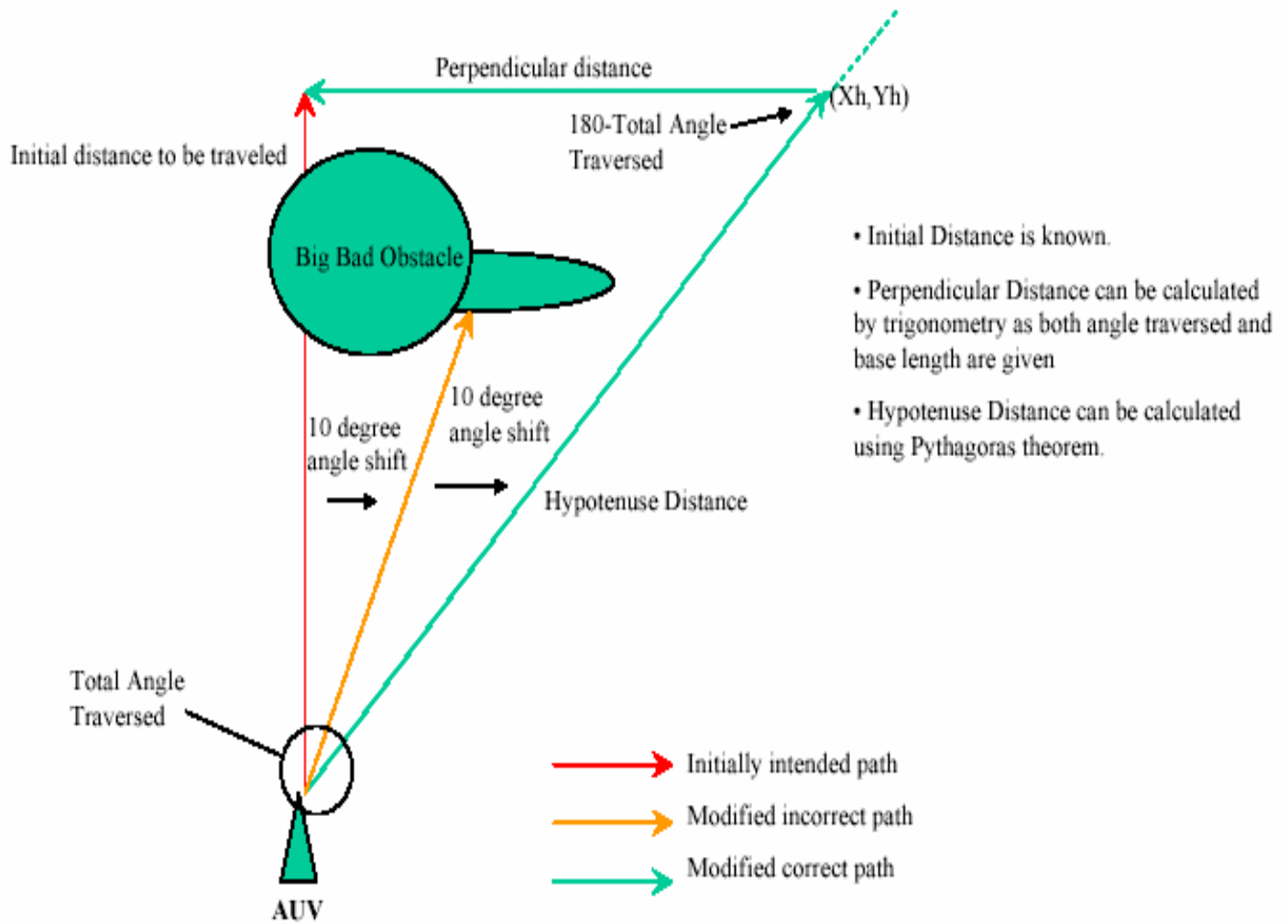
Forward and Backward Motion and Obstacle Avoidance

AI Motor Control Decision Procedure

1. AI gets input on which heading (say 6ft forward)
2. Queries Primary Sensor for current position.
3. Queries Secondary sensor for Obstacle detection in straight path.
4. If obstacles detected, turns 10 degrees (max 45 degrees allowed) to right and goes to step 3.(this step is open to discussion)
5. Once no more obstacles detected, calculates hypotenuse length and total angle traversed, and perpendicular distance (see obstacle avoidance diagram for details)
6. Starts the two Horizontal Thrusters, queries Primary Sensor and compares it to final destination.
7. When (Xh,Yh) reached, turns heading to (180-total angle traversed). And move perpendicular distance maintaining current heading.
8. If no obstacle detected then start both Horizontal thrusters, and query primary sensor periodically till distance covered.
9. END



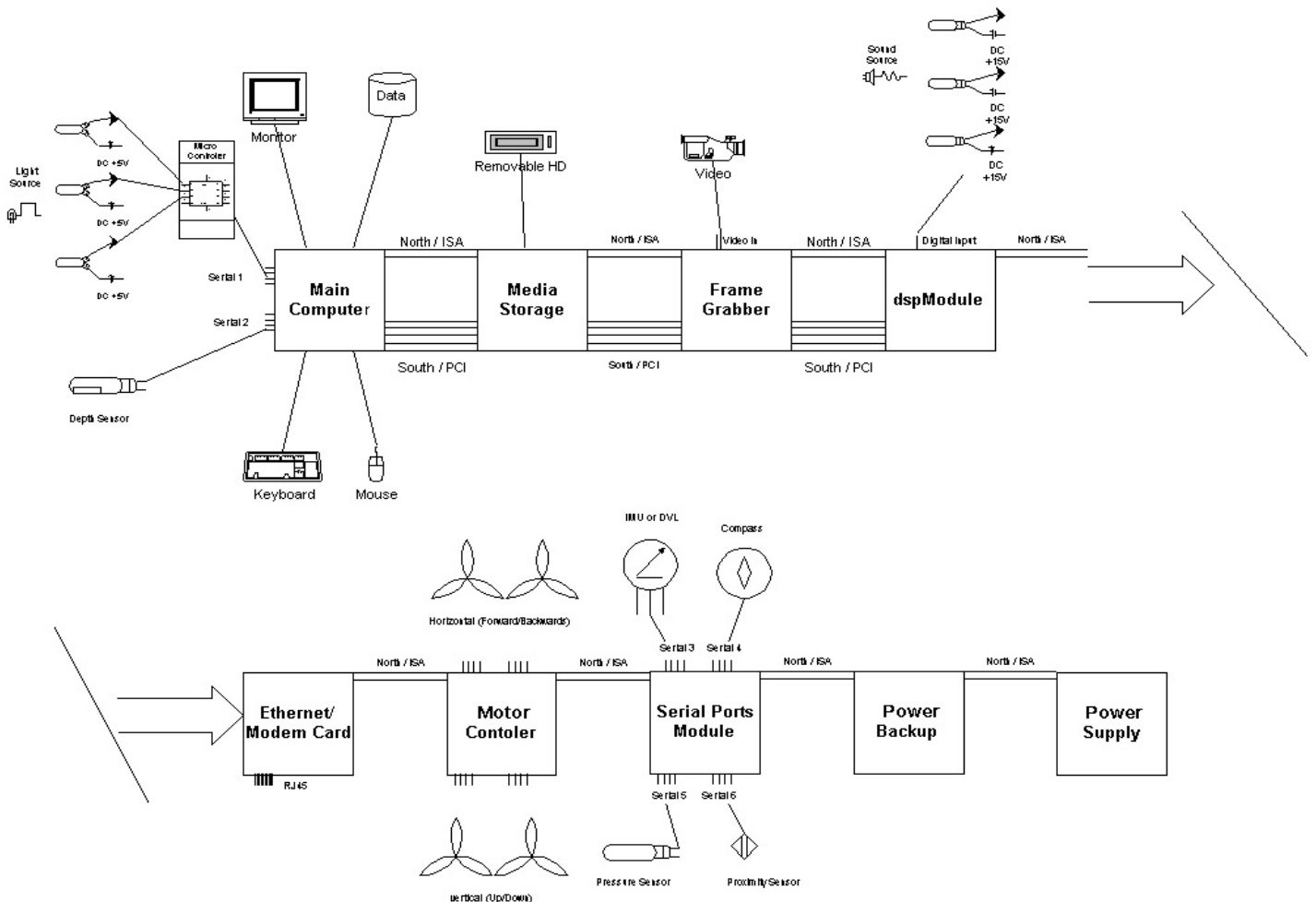
Obstacle Avoidance Diagram



Onboard Computer System

For the 2003 AUV, we will upgrade our Pentium 150 based single board computer to a PC/104 form factor stack. Many of the sensors, including the IMU, sonar, digital compass, and hydrophones will be interfaced through RS232 serial ports. We will use a frame grabber to interface the camera. For storage, we plan to upgrade from the hard disk used in previous years to flash memory because it is small and uses less power. To interface this flash memory, we will use a standard PCMCIA module available for the PC/104. We will have an extra PCMCIA port available on this card, and may use it for a wireless Ethernet card, as the ability to troubleshoot the submarine without opening the hull will shorten testing time. The following is the PC104 Computer layout.

Figure 3: Computer System Diagram



The computers will run a brand of Unix that will suit the needs of the system best, due to Unix's high modularity and ease of handling. The primary language will be c for its efficiency and compatibility with Unix systems. The main programs that will be needed for the data-gathering part will be a task handler, watchdog, and process scheduler, the subprograms will be specific to each of the components; from mission-specific sensors (hydrophones, navigation sensors, internal environmental sensors (temp, link, watchdog, status, etc...), sonar, video, and battery status. The main programs that will be needed for the control task will be the task handler, watchdog, and process scheduler, the subprograms will be for the control systems; servo controller, modem(if any) and the LCD display. The over lap of the main systems will allow for less programming, but the subsystems will each need to be designed specific to the goals of each systems who logic or algorithms will come mostly from the teams assigned to each system. It will be the job the programmers to ensure that these specific programs run the most efficiently.

Motor Control System (Servos and Thrusters)

The thrusters that will be used in this require a low battery usage, taking this into consideration, the MotorGuide ET22 will only use 12v DC at only 33 amps of power. The servo drive (which consists of the servo controller and the motor) controls the status of the thrusters. The controller will have the task of setting the servo motor with the torque and speed that is required for thruster to vary its speed and direction of movement. The Mini SSC II provided by Scott Edwards Electronics, Inc. will be used as the servo controller while the Minn Kotas will be used for thrusters.

Last years design called for 6 thrusters, and six servo controllers. After considering various stability issues we decided to go with 4 thrusters. 2 for vertical motion and two for horizontal motion. This would cut down power requirements as well as simplify hull design.

Power System

The power supply for the AUV has a simple breakdown into the following systems, the thruster's/servo power, the on-board computer and sensors, and the kill switch. The development of these systems will be based on both a review of last years work by the ECE AUV group and a review of the technical journals of other schools entries to the international competition. The current the system design entails the following requirements from last year.

- There is no need for multiple power sources due to the DC/DC converters purchased last year. All power requirements can be handled form two (one 12V/ 17Ah and one 12V 42Ah) batteries.
- The power sources are rated at 1.2 hours worth of power for the sub. Time requirements are 30 minutes for the competition, so this gives a safety factor of 2 for the power supply.
- A kill switch must be installed to stop the operation of the sub if the officials feel it is necessary. This switch must be installed on the sub where it is easily locatable and removable.

This year we are considering replacing the standard lead acid batteries with light weight Li Ion batteries. This decision affects our design drastically as it reduces the weight/size of the AUV by 30-40%. This is a highly positive outcome of switching batteries but there is a downside as each Li Ion battery costs \$500(approximately). The total upgrade cost is going to be \$2200. We are also investigating the possibility of using Lithium metal hydride batteries in the hull as they would be significantly cheaper, but would increase weight considerably.

The current system is using Li Ion batteries made by Lithion Inc. These are a series of lightweight Lithium Ion batteries made especially for US military and NASA.

Advantages

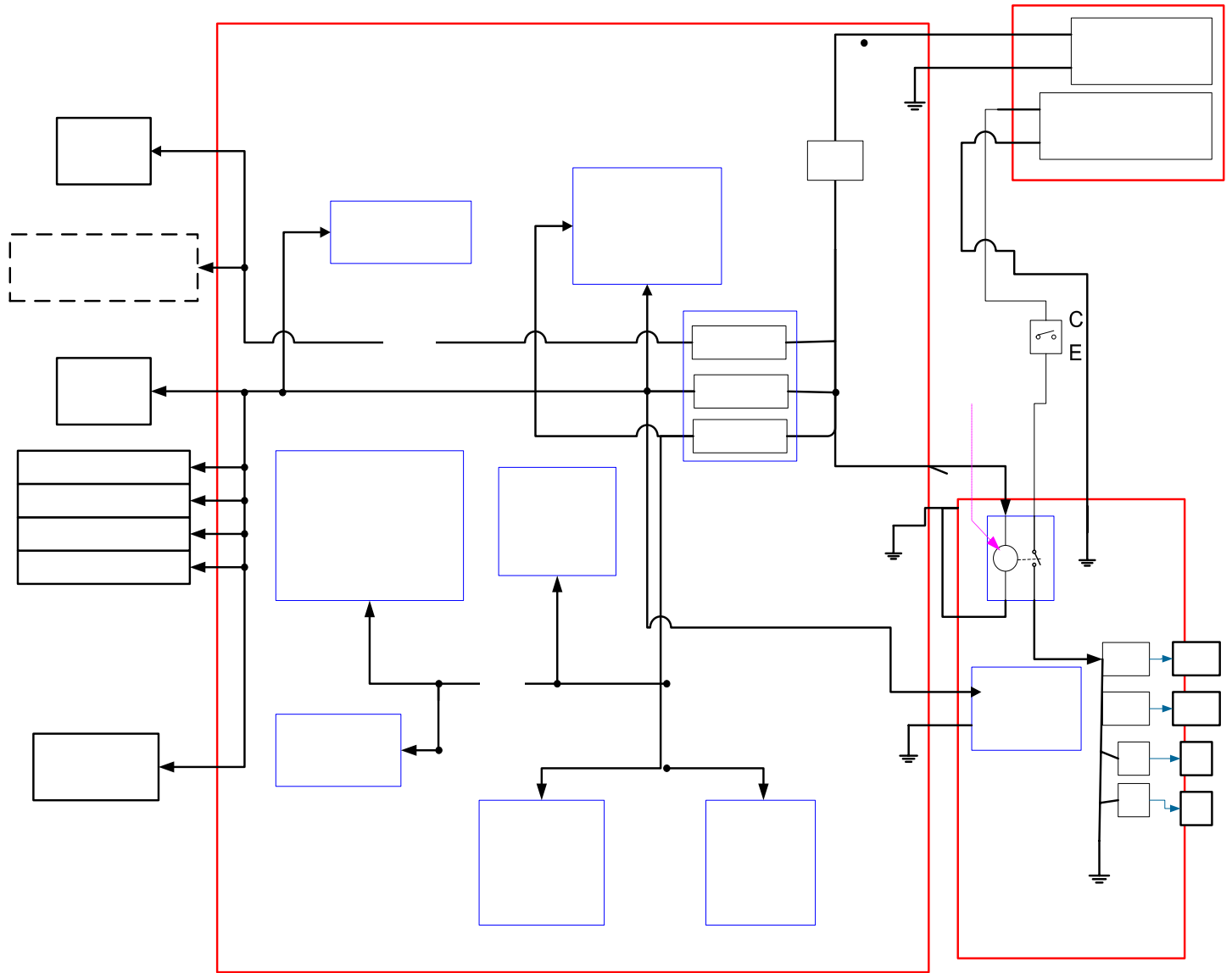
- Extremely lightweight: Total battery mass will be about 3480 grams or 3.48 kgs.
- Standard connection terminals

The set up would require the following parts

- 3 INCP 77/25/63 Batteries
- 3 INCP 95/28/151 Batteries
- 6 sets of battery terminal connectors

This system would require that the batteries be hooked up in series to meet the minimum requirements. This would be the 3 -10.5 Amp hour batteries hooked up in series and the 3-35 amp hour batteries in series.

Figure 4: Power System Wiring Diagram (Using Li Ion Batteries)



Additional Safety Equipments

Temperature Sensors: are placed in various parts of the AUV's interior and are used to monitor the temperature of various subsystems within the hull of the AUV, in order to avoid heat damage.

Leak Detectors: are used to detect breaches in the hull. If a breach is detected the onboard computer is instructed to abandon the mission and return the AUV to the surface in order to minimize damage to internal components.

Kill Switch: the kill switch is a part of the power subsystem. It is used as a manual override to the power supply in case something goes wrong with the AUV, and a diver has to go and retrieve it. It is connected to the main power line and is mounted externally on the hull.

Hull Design and Construction

The design and construction of the hull of the AUV is one of our major challenges. This year, we have analyzed previous years hull designs and came up with an extensive set of requirements for the hull. Also a buoyancy calculation spreadsheet was developed in order for the hull to meet with the competitions standard requirement of +2% buoyancy.

Based on these requirements, the hull design team has drafted 3 design concepts for the hull. The first of these designs is made of an 8in hull and was designed to fit all the existing components. This design was generated as a worst case scenario: If we are unable to procure any new components for the AUV.

The end caps and sealing design for the hull is being done in collaboration with Davidson laboratory's Richard Sheryll, who is an expert in high pressure sealing methods. We are going to use a plug type static O ring seal for the end caps. This end cap is going to be machined out of Aluminum, as it would also double as a heat sink.

The main hull will consist of clear PVC tubes, with mounting rails for mounting various components inside. The clear PVC enables us to discover any faulty wiring, leaks, and other problems without disassembling the hull.

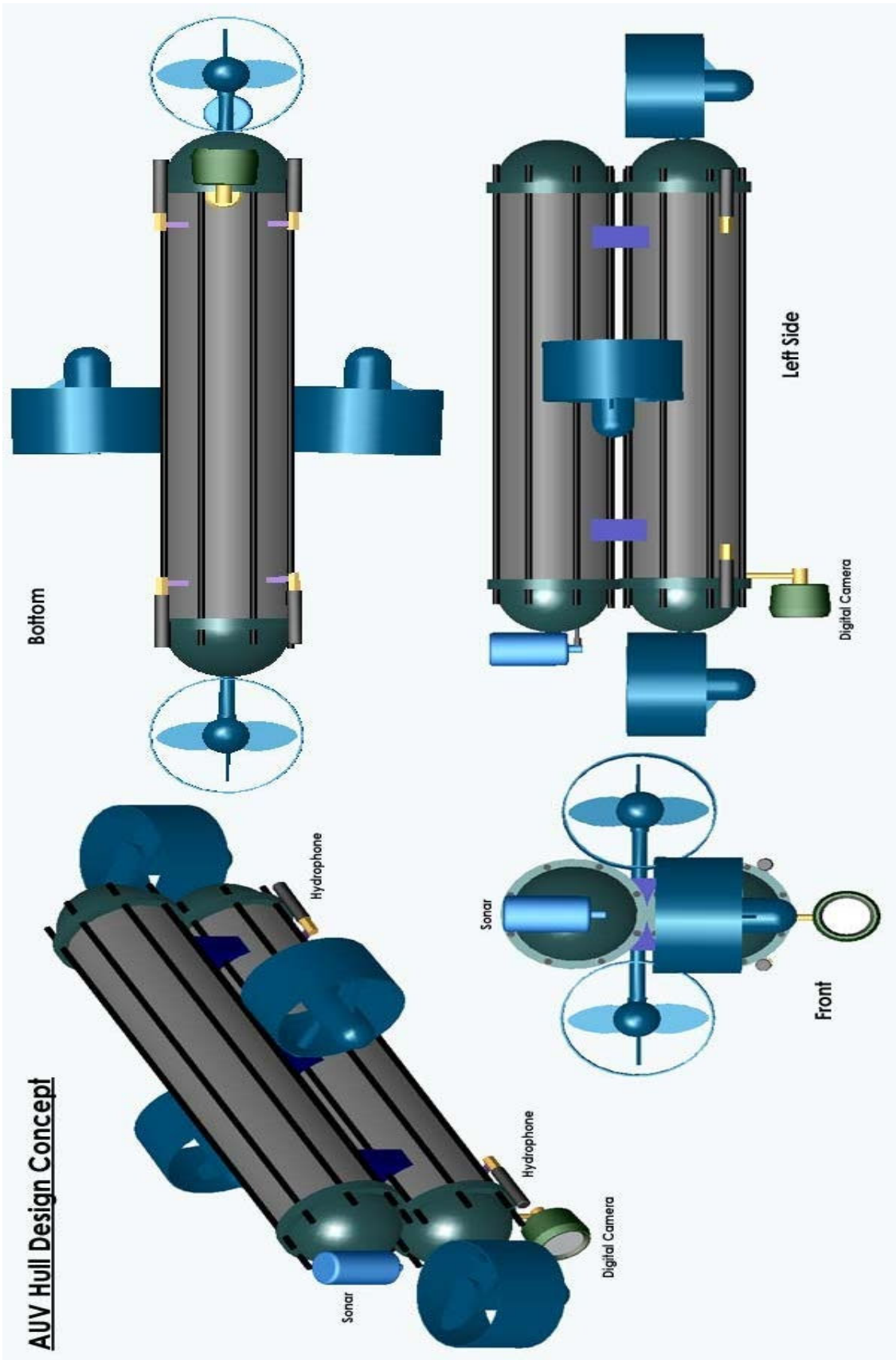
Hull Design Concept 1

The design consists of dual 8in hulls 4ft in length. The batteries and the servo controllers are placed in the bottom hull, and the computer and navigation equipments are placed in the top hull. This is a safe design as it ensures that the navigation sensors are not affected by the magnetic fields created by the batteries.

There are horizontal rods running along the length of the hull in order to hold the end caps in place. These rods also provide us with mounting points for various equipments like the hydrophones, sonar altimeter, and pressure transducer. The two hull tubes are separated and held in place by aluminum spacers machined by machine shop. These spacers act as rigid mounting points for heavy equipments like the thrusters,

The downside to this design is that it is very heavy, weighing in at over 100kgs. The weight causes considerable complications to the design of the systems, especially the thrust requirements to move the AUV underwater. It requires a lot of power to move a heavy machine, which in turn, requires a larger battery, which is neither economically fiscal nor spatial. Like a cycle, excessive weight leads to excessive thrusters, which requires excessive power, which inevitably leads to excessive spending.

The size too, seemed to make things more difficult. Because the AUV is going through an obstacle course, the large size leaves little tolerance for error. Whether it's barely fitting through the starting gate, or just avoiding the obstacles themselves, the large size seems to be an added concern and handicap. Also the drag force is proportional to both the shape and surface area, more power is required to overcome these unnecessary forces, lending more to the argument of excessiveness, as mentioned above.



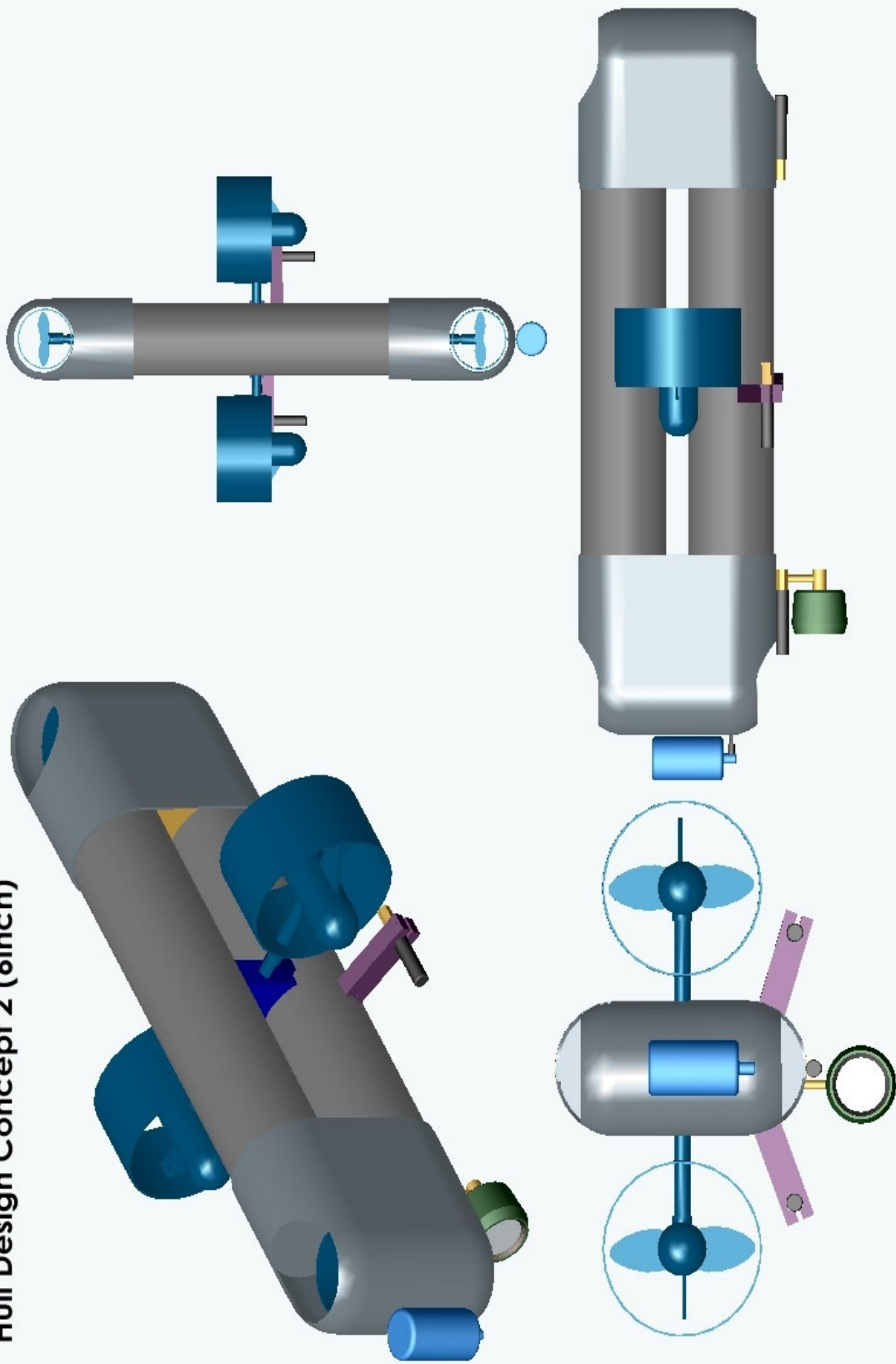
Hull Design Concept 2

The second design concept incorporated the new Li Ion Batteries and the PC104 Computer into the hull and abandoned the old lead acid batteries and the old ATX computer system. This reduced the hull tubes size from 8inch to 6inch, and also the weight of the batteries from (47+20) 67lbs to a mere (1+1+1+1+1) 5lbs. This drastic reduction in weight also affects buoyancy, as the hull size can be shortened. We also incorporated a cover over the end caps made out of fiberglass. This would enhance our design by reducing drag.

The results is a smaller lighter compact hull, with a total weight of 63Kgs, comparable to MIT's ORCA design which weighs in at 50kgs.

The internal mountings will be on an aluminum tray, which will be connected to one of the rear end cap. The tray would also double as a heat sink transferring heat generated within the hull, to the water body. There will also be a common point on each of the two hull tubes for wires going in and out of the hull. These connectors will need to be watertight, which will be facilitated by the use of waterproof connectors.

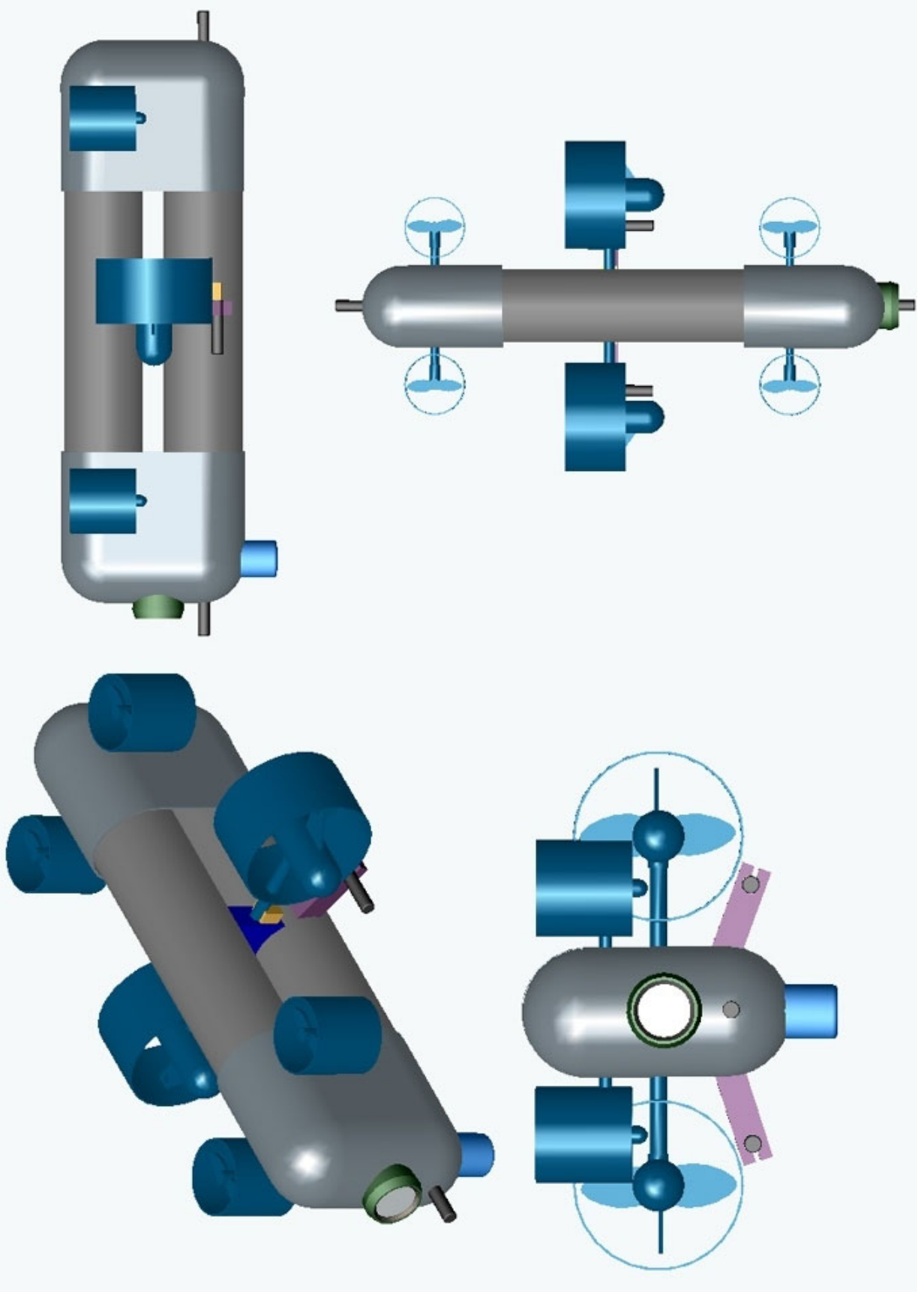
Hull Design Concept 2 (6inch)



Hull Design Concept 3

The third concept also uses the 6inch hulls, and spacers. The major difference from the second design concept is that it uses 4 Vertical Thrusters mounted to the top hull. This provides additional stability to the AUV, and also frees up the front and back end caps of AUV for mounting sensor equipment. This was a problem with the second design concept as the vertical thrusters would generate noise which would affect the sensor reading. Freeing up the end caps also provides easy access to the internal components of the hull. This in turn would significantly reduce servicing time for the hull.

Hull Design Concept 3 (6 inch)



Components List & Budget

The following is a comprehensive list of components that are going to be a part of the current AUV Design. The first table lists the make and model of the existing components. The second table is a list of components and other expenses for which additional funding is required. This list however will grow as the design is further refined. Also, purchasing additional sensors may be required when the mission specifics are released by AUVSI in February-March.

Component List 1: Already Purchased

Category	Item	Note	Price	#	Cost
Altimeter	Tritech PA500/6-ALRA Sonar Altimeter	Purchased previous competition	-		
Depth	Ashcroft K1 Depth sensor	Purchased previous competition	-	1	-
Hydrophone	Xilinx Student Edition with Foundation 2.1 software and XS40-005XL FPGA prototyping board	Purchased previous competition	\$154.00	1	-
Hydrophone	XST-1 Xtend board	Purchased previous competition	\$99.00	1	-
Hydrophone	LTC1562CN Active RC Quad Universal Filter	Purchased previous competition	\$10.35	2	-
Hydrophone	LTC1116 Comparator	Purchased previous competition	\$4.00	4	-
Internal	Liquid Level Sensor	Purchased previous competition	\$9.95	1	-
Internal	LM35DT Temp Sensor	Purchased previous competition	\$2.79	1	-
Light Sensor	OOPIC II Starter Package	Purchased previous competition	\$69.00	1	-
Light Sensor	Siemens SFH 205f pin photodiode	Purchased previous competition	\$1.25	4	-
Multi-role	PIC 16F84A	Purchased previous competition	\$5.95	2	-
Multi-role	MAX232-RS232 driver	Purchased previous competition	\$2.25	3	-
Multi-role	General-Purpose IC PC Board	Purchased previous competition	\$1.29	2	-
Multi-role	Resistor & Potentiometer	Purchased previous competition	\$10.00	1	-
Multi-role	Capacitor	Purchased previous competition	\$5.00	1	-
Compass	Tri-m TCM2 Digital Compass	Purchased previous competition	-	1	-
Navigation	Crossbow IMU400CB	Inertial Measurement Unit, Purchased previous competition	\$4,000.00	1	-
Propulsion	Novak Super Rooster	Electronic Speed Control, Purchased previous competition	-	4	-
Propulsion	Minn Kota trolling motor	Thrusters, Purchased previous competition	-	4	-
Propulsion	Scott Edwards Electronics Mini SSC II	Serial Servo Controllers, Purchased previous competition	-	1	-
Power	XpiQ PD -110 DC/DC converter	Purchased previous competition	-	3	-

Component List 2: Funding Required

Category	Component Name	Price
<u>Computer System</u>	PC/104 plus processor	
	Advanced Digital Logic MSMPSEV	\$ 527.00
	Advanced Digital Logic smartCoreP3-700	\$1,103.00
	PC/104 Plus Video Capture Card	
	Real Time Devices CM7326	\$ 455.00
	Underwater Camera with IR illumination	
	RF Concepts CC50C-18	\$ 275.00
<u>Hull Parts</u>	6inch Clear PVC Pipes (10ft)	\$ 200.00
	Custom machined sensor mounts	-
	Custom machined end caps + O-Rings	-
	Watertight Connectors	\$ 300.00
	Fiberglass + Moulds for Streamlining	\$ 200.00
<u>Batteries</u>	Lithium Ion Batteries	\$2,000.00
<u>Competition Expenses</u>	Entry fee	\$ 500.00
	Van rental for transport	\$1,400.00
Total Expenses - Performance upgrades and Competition Expenses		\$6,960.00

Conclusion

This year, the AUV project is progressing steadily. The design of the hull is 80% complete, and will be ready for prototype testing by end January 2003. Programming of the Navigation Autopilot program has begun. Navigation equipment testing on a subsystem basis is already taking place. Since we are employing a number of new systems like the multi beam scanning sonar, the system integration team will play a big role in the successful completion of the project. Next years plan is to integrate all these individual subsystems into the AUV, and conduct testing. Once the mission specifics are in hand, the team will concentrate on modifying the base design to meet them. If all goes as planned, the 2003 AUV will be a strong contender at the 6th Annual AUVER Underwater Competition.