MATE / MTS National ROV Competition

From the Depths of the Oceans to the Far Reaches of Outer Space

Johnson Space Center
June 17-19, 2005

Ranger Class Technical Report

Proletariat Torpedo ROV

Thomas Jefferson High School for Science and Technology
~ ROV Team ~

Lucas Brown
Mike Plasker
Meghana Sharafudeen
Yen Trinh
Ruixin Yang
Lisa Wu, *Sponsor*
Justin Manley, *Mentor*
Ron Anderson, *Mentor*

Submitted May 27, 2005

Abstract

This technical report describes the *Proletariat Torpedo*, a remotely operated vehicle (ROV) built by five senior Oceanography Technology Lab students at Thomas Jefferson High School for Science and Technology in Alexandria, Virginia.

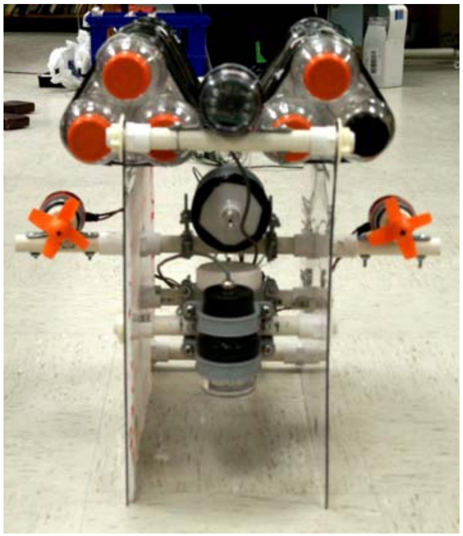
The 2005 MATE / MTS National ROV Competition mission is an Underwater Olympics. The *Proletariat Torpedo* ROV has been designed to complete three specific underwater tasks that MATE created to simulate real-life situations; shutting an oil valve (capping an oil well in the Gulf of Mexico), inserting a probe into an open port (repairing and re-establishing a communications link), and attaching a module to the side of a mock telescope (installing an instrument module on the Hubble Space Telescope). The vehicle is equipped with an electromagnetic claw and a simple control system designed and built for efficient completion of the tasks.

As the competition is designed to incorporate the emerging advances in the fields of marine and space technology, the design and construction of an ROV that completes these tasks required a working knowledge of electronics, robotics, prototyping, CAD, applied physics, and oceanography. This technical paper contains the *Proletariat Torpedo* ROV's design rationale, challenges the team encountered, lessons learned, ideas for future improvement, and a description of the fascinating field of ocean fiber optics.

TECHNICAL REPORT

The Proletariat Torpedo

Description of ROV



Lucas Brown, 2005

Fig.01 – *The ROV.*

The *Proletariat Torpedo* is 50 centimeters long, 11 centimeters wide and 40 centimeters high. It is designed to efficiently complete three mission tasks:

- **Task One –** *Shut off an oil valve by turning it 90° along a horizontal plane***.** The *Proletariat Torpedo* will approach the task and use the strength of its forward thrusters to push the valve shut (the thrusters can provide much more force than the necessary 1N). The frame is extended at the front to provide even vertical contact with the bar valve.

- **Task Two -** *Transport and insert a telecommunications probe into a open port on a horizontal surface.* The ROV's claw device holds the probe as it is taken to the task site. Once there, Camera Two (with a downward view) is used to position the ROV above the task and guide the vehicle down until the probe is inserted into the port. When power is sent to the claw, the device opens and releases the probe.

- **Task 3 -** *Attach an instrument module to a vertical Velcro™ target 10 centimeters in diameter.* The ROV's claw device holds the module as it is taken to the task site. Camera One (with a forward view) is used to position the vehicle and the module in front of the target and guide both until the probe is attached to the target. When power is sent to the claw, the device opens and releases the probe.

ROV Design Rationale

A. Frame

Basic Requirement: A stable and durable structure.

Other factors considered: Overall drag, weight.

The sides of the vehicle consist of a lightweight sheeted plastic chosen for minimum weight and flexibility in attaching components. The two sides of the vehicle are interconnected through ½ inch PVC pipes onto which cameras, thrusters, solenoid, and claw are attached. Holes can easily be drilled in the frame for attachment of additional components or repositioning of existing systems. The drawback to having solid sides is an increase in the vehicle’s overall drag. To counteract drag while still keeping the original frame structure, the size of the ROV was drastically minimized by placing the small forward thrusters outside the frame. The width of the ROV was reduced from 44 cm to 11 cm.

B. Control System

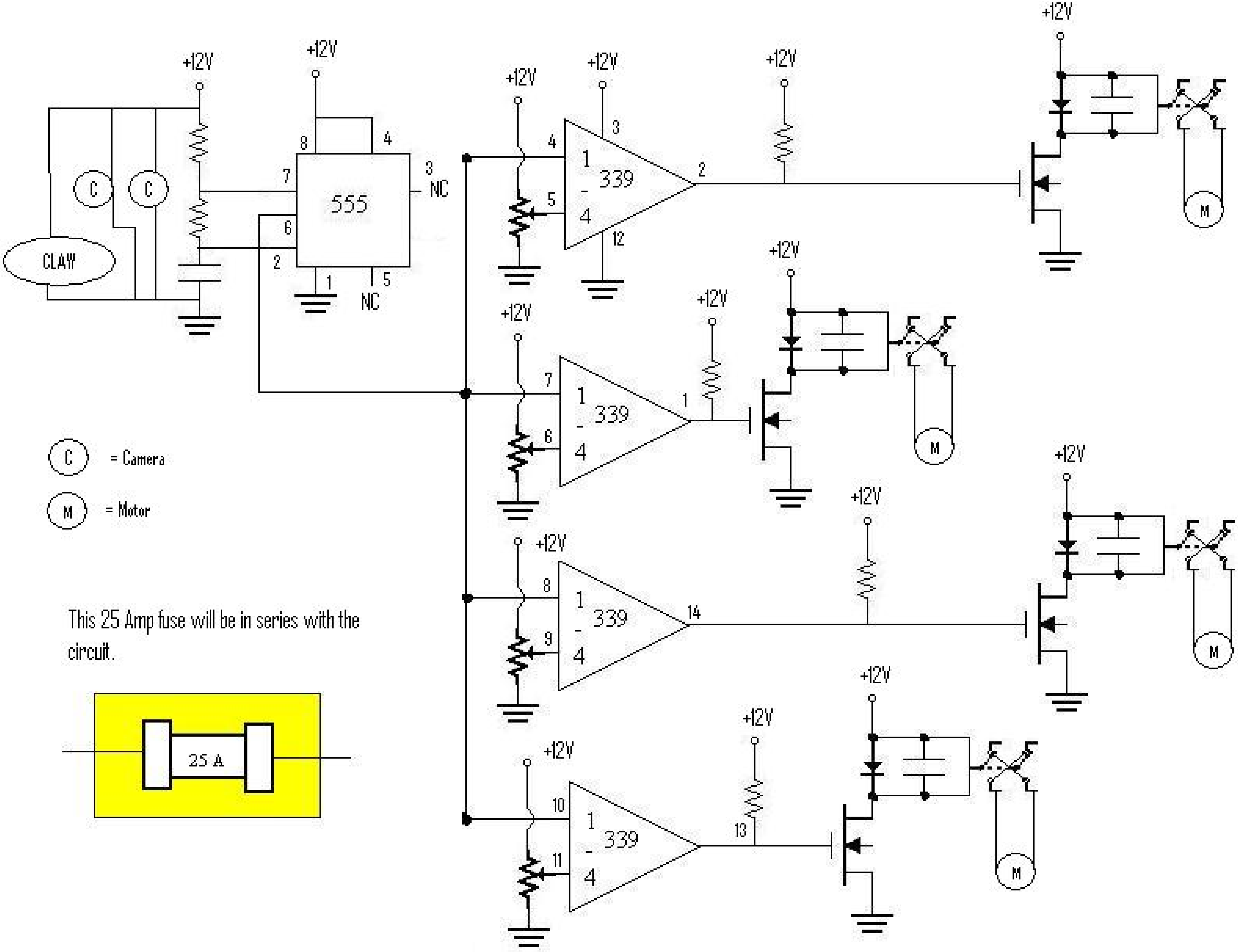
Basic Requirement: Simple ON/OFF switches on all electronic systems (cameras, manipulator, thrusters).

Other factors considered: Speed control, safety, manageability/driver convenience, maintenance (simplicity v. complexity).

Due to budget constraints, the controller is simple and entirely student built. Each camera has an on and off switch, as does the solenoid (electromagnet) which controls the claw. Each thruster also has an on and off switch, along with a speed-control dial that is attached back to a potentiometer within the circuit. All the components are attached to one interface for driver convenience.

For ease in wiring circuitry, a custom-made circuit board with basic wiring was designed on the CAD program and printed. This made it relatively easy to drill only necessary holes and solder on components, and dramatically cut down on time spent wiring and building the circuit.

The electrical schematic (Fig.02) can be found on the following page.



C = Camera

M = Motor

This 25 Amp fuse will be in series with the circuit.

C. Propulsion System

Basic Requirement: The ability to move up and down, move forward and reverse, and turn.

Other factors considered: Speed versus maneuverability, system weight and amperage draw.

Lucas Brown, 2005

Fig.03 – *500 GPH forward right thruster with 1.5” propeller.*

The thrusters are converted RULE bilge pumps. Unlike most thrusters, bilge pumps draw in water instead of pushing it. However, the motor itself can be used for either task. Therefore it was simple to cut open the RULE bilge pumps and create aluminum propeller adaptors to fit on the motor shafts. Propellers were attached to complete the transformation of the pumps into functional thrusters.

Along the x-y plane, the vehicle has three thrusters (a central 2000 GPH thruster and two 500 GPH on either side) for forward motion and turning. The 2000 GPH motor is for forward speed while two 500 GPH thrusters are for maneuvering. All thrusters are placed so that their propellers, and therefore the axis of rotation, are at the center of the vehicle. As a result, the ROV can make tight circles around this axis of rotation, an indication of precision turning ability. A single vertical lift thruster is positioned at the center of the ROV for up and down movement.

Thrusters working underwater to move the ROV have a much greater amperage draw than that which was stated on their bilge pump casings. A number of factors contribute to this, including drag caused by the propellers and the vehicle itself. Designing the ROV circuit and determining wire gauge required knowledge of the exact amperage draw. Using an ammeter, an experiment was conducted to determine the exact amperage draw of each thruster in the propulsion system with various propellers.

Compared Amperage Draw of Select Thruster Propellers

Plane	GPH	1.5” props	3.5” props	5” props
x-y	500	3.82 A	---	---
x-y	500	3. 88 A	---	---
x-y	2000	---	12.24 A	14 A

Z	2000	---	12.89 A	14.67 A

Fig.04 - *Results of the amperage draw experiment conducted for selection of ROV thruster propellers.*

Based on these results, it was decided to use 3.5” props for the 2000 GPH thrusters and continue using the 1.5” props for the 500 GPH motors.

D. Manipulation System

Basic Requirement: The ability to hold and insert a telecommunications probe into an open port below the vehicle and the ability to hold and attach an instrument module to a target in front of the vehicle.

Other factors considered: System efficiency and amperage draw

Photo by Lucas Brown, 2005

Fig.05 – *Claw powered by electromagnetic solenoid.*

A four pronged claw (designed, laser-cut and built) at the front of the vehicle is controlled by a solenoid situated at the back. Since teams can place any instruments in vehicle manipulators at the beginning of each task, all a manipulation mechanism requires is the ability to open underwater. The most efficient way to accomplish this is to have a device that stays closed until it is switched on. The *Proletariat Torpedo*’s manipulation system is designed so that the electromagnet pulls back when power is provided, opening the claw and releasing the object being held.

The main problem encountered with use of a solenoid is the necessitated waterproofing of moving parts. This issue was resolved by the placing of a cap of a flexible, waterproof rubber material over the front of the solenoid. The flexibility of the rubber made it possible to seal the claw cable to the material so that both the cable and the rubber would move together.

E. Cameras

Basic Requirement: A forward view for steering, and a downward view for steering and completion of Task Two.

Other factors considered: System efficiency and weight.

Photo by Lucas Brown, 2005

Fig.06 – *SeaView® underwater video camera*

The ROV has two SeaView® Super-Mini black and white underwater video cameras with white infrared capability, which enables the cameras to automatically adjust video input with varying light levels. Camera One faces forward for steering and forward view while Camera Two is positioned almost directly under the claw for a downward view of the tasks. Camera One is situated approximately 6 centimeters above the claw so that the driver can see both the very edge of the 10 centimeter diameter instrument module in Task 3 and the Velcro® target. Camera Two is situated below and just to the side of the claw so that it has both an orthographic view of the telecommunications probe when it is held by the claw and a view of the open port in Task 2. The cameras have RCA video signal plugs and are connected to the 5” SONY AC/DC monitor by BNC adaptors.

F. Tether

Basic Requirements: Power needs to be conducted from the battery and control system through the water to the various electronic vehicle systems (propulsion, manipulation, visual).

Other factors considered: Tether flexibility and drag.

Three multi-wire cables conduct power through the tether and to the thrusters and solenoid-powered claw. The tether also contains two coaxial cables connected to each of the vehicle’s cameras. Multi-wire cables were chosen because they are more flexible and manageable than individual wires.

G. Ballast System

Basic Requirements: Neutrally buoyancy and inherent stability.

Other factors considered: System efficiency, depth control, pitch, drag.

Photo by Lucas Brown, 2005

Fig.07– *Gatorade ballast on right side of ROV frame*

The ballast system for the *Proletariat Torpedo* ROV has three main components. Six Gatorade® bottles, three on each side of the frame, provide the main flotation for the vehicle. They are streamlined and can be partially filled with water to adjust flotation. Though depth limitations are introduced by the use of Gatorade® bottles, the bottles are perfect for shallow water ROVs because they are cost-efficient and surprisingly effective.

Small holes drilled along the bottom of the frame allow for attachment of lead or high-density weights to the frame for ease in adjusting for neutral buoyancy. A length of ½” clear plastic tubing, stopped at both ends to trap air, runs along the tether to make it neutrally buoyant. This method of buoyancy for the tether makes the tether easier to manage.

Challenges

Though any team faces numerous challenges throughout the design and construction process, a few challenges affected our entire project. The hurdles the team had to overcome to complete the *Proletariat Torpedo* ROV are listed below:

- **Lack of electronics experience –** The members of the TJ ROV team did not have the necessary electronics experience to build the circuit and control system envisioned. To gain these basic skills and expand our knowledge in the electronics field, we scheduled information meetings with electronics teachers at school, researched extensively, and learned much through trial and error. We started the year by building a simple prototype of an ROV. Before finalizing designs, the team conducted a technical design review with mentors and other scientists. Every member of the team participated regularly in the electronics process in order to ensure equal experience.

- **Cost –** The Oceanography Lab has a $1500 budget for all student projects and the ROV team received approximately $250. As a result, cost-efficiency was a very high priority for our vehicle and this was necessarily reflected in our design. The ROV's control system and propulsion systems are not store bought and the ballast system incorporates Gatorade® bottles recycled after student use.

- **Time –** The senior technology lab is a required course at Thomas Jefferson that meets twice a week for 90 minutes and once a week for 45 minutes. Due to heavy course loads and involvement in numerous extracurricular activities by team members, it was extremely difficult to find time to work outside of class, a must for this competition.

- **Lack of equipment and other resources –** Budget limitations led the team to create many of the things most teams buy, such as thrusters. Unlike the Robotics or Prototyping Tech Labs, the Oceanography Tech Lab contains little equipment other than aquariums and other marine-biology related supplies. The team had to rely on the generosity of other teachers with tools such as lathes, laser-cutters, taps, drills, and jigsaws and had to work around additional teacher schedules. Paired with the time constraints outlined above, this was an issue because the team was often unable to work. The only place the ROV could undergo underwater testing was CarderRock Naval Research Center. These visits had to be scheduled weeks in advance and we had to drive 45 minutes to reach the facilities. For basic underwater testing that involved very contained movement, a team member finally brought in a horse trough which we used for shallow water testing.

Photo by Lucas Brown 2005

Fig.09 – *Horse trough and temporary underwater testing site*

Troubleshooting Techniques

When designing the *Proletariat Torpedo* ROV, we realized we needed to avoid electronic problems, especially during missions. The following precautions were implemented:

- The team examined all possible scenarios and designed the vehicle to use a maximum of approximately 20 amps in a single pulse.
- Any motors purchased came with built in fuses.
- While waterproofing electronic components, our team motto was “when you think it is waterproof, waterproof it some more.” Though our solenoid appeared to be waterproof when we bought it, we made sure to waterproof it ourselves anyway as a precaution because we were not absolutely sure. The consequences of it not being waterproof far outweighed any time trade off.

After a test-run at CarderRock, the team decided to incorporate the safest gauge of wire in the tether. Originally we used 18 gauge wires for our 500 GPH motors that drew approximately 4 amps underwater and 16 gauge wires for our 2000 GPH motors that drew approximately 13 amps underwater. When testing, wires soon became too hot to touch, especially on the larger motors. We research the American Wire Gauge (AWG) Table for a solution to our problem.

WIRE GAUGE SELECTION TABLE

Circuit Amperes		**Circuit Watts**		**Wire gauge (for length in feet)**						
6V	**12V**	**6V**	**12V**	**3'**	**5'**	**7'**	**10'**	**15'**	**20'**	**25'**
0 to 2.5	0 to 5	15	30	18	18	18	18	18	18	18
3.0	6	18	36	18	18	18	18	18	18	16
3.5	7	21	42	18	18	18	18	18	18	16
4.0	8	24	48	18	18	18	18	18	16	16
5.0	10	30	60	18	18	18	18	16	16	16
5.5	11	33	66	18	18	18	18	16	16	14
6.0	12	36	72	18	18	18	18	16	16	14
7.5	15	45	90	18	18	18	18	14	14	12
9.0	18	54	108	18	18	16	16	14	14	12

10	20	60	120	18	18	16	16	14	12	10
11	22	66	132	18	18	16	16	12	12	10
12	24	72	144	18	18	16	16	12	12	10
15	30	90	180	18	16	16	14	10	10	10

Fig.10 – *AWG Chart used to make decisions about wire gauge. The chart can be found on the internet at http://www.rbeelectronics.com/wtable.htm*

The team chose to use 16 gauge wire with a capacity of up to 10 amps for our smaller motors and 12 gauge wire with a capacity of up to 18 amps for our larger motors.

Next we reexamined the circuit board. When the board was originally drawn on CAD, some connections and the positive and negative base wires had been drawn too small for the amperage draw across them and the heightened resistance would probably result in a burned-out circuit. We reprinted and re-wired the circuit board, carefully insulating any bare wires.

Our experience with a shorted circuit, smoking wires, and burnt fuses has taught us to be cautious at all times. With the safety nets built into the ROV design and the added precaution of fuses within the circuit, nothing should go wrong with the *Proletariat Torpedo*’s electronics.

Lessons Learned

As stated in the “Challenges” section of the technical paper, the entire project has been a tremendous learning experience for each member of the TJ ROV team. We have developed a working knowledge of the CAD program and of various pieces of machinery such as the lathe and the laser-cutter. We have learned how to tap and drill, use set screws and socket head screws, and draw precise engineering diagrams. We have expanded our knowledge of basic and higher-level electronics, applied physics, prototyping and robotics, and have discovered the field of ocean engineering. Among the most important lessons learned were the following, which, like learning how to budget and how to communicate, can be used throughout our lives.

- **Sometimes the best way to figure out whether something works is to just do it**. There was often too much discussion between our five team members, we would get bogged down in details and nothing would get done. For example, we spent a lot of time theorizing about the capabilities of our manipulation device but later realized it would be easier to work out issues if we laser-cut a prototype into plywood and tested it.

- **Be specific**. As we looked back at our research notebooks at the end of the year, we found early “to-do” lists that contained items such as “finish circuit”. Such a broad and extensive task would usually not get done in the time allotted and we often found ourselves dejected when it appeared we had failed to adhere to our schedule. We soon realized that more specific lists allowed for more efficient completion of tasks.

- **Project Management is key**. The team found itself having to strike a delicate balance between teamwork and having too many people on one task. We solved this problem by having team leaders who not only did their own tasks, but supervised other team members and made sure everyone knew what was happening. We also used our online web log and a group email account to keep everyone, including our mentor and sponsor, updated.

Future Improvements

The team sat down and discussed specific future improvements to each ROV system. These ideas are a product of the lessons we have learned over the year:

Frame – Reduce the drag of a solid side while still maintaining the flexibility in attaching components provided by solid sides. It might also be safer for the ROV to have sturdier material for the frame as well, as the current design requires careful handling of the vehicle on deck.

Control System – Buy a control system if funds are available. In addition, it would behoove a future team to purchase more easily manipulated switches and potentiometers that are more responsive to slight force from the driver.

Propulsion System – In-depth research and multiple design ideas on propeller pitch and blade length would be useful for any team building ROV because these factors directly affect thrust.

Manipulation System – Increased degrees of freedom to allow for variation in completing other tasks.

Preparation – Our lack of knowledge about electronics limited our ability to efficiently design and construct circuitry. Future teams should research the fundamentals of electronics before starting to build their ROV. Basic areas to research include wiring skills, resistors, fuses, diodes, the relationship between current, voltage, and power across a circuit, and even how to use a multimeter to measure voltage drops or current draw.

Other extensive research and preparation would also be helpful before a team begins to design or build an ROV. It would have been helpful to us this year if we talked to teachers about use of equipment and outlined schedules early on to avoid conflict and delay at crucial moments. A team should also get into the habit of documenting the mathematical rationale for most design decisions instead of just picking whatever method or design makes logical sense. For example, when making decisions about thrusters, important factors to consider include amperage, thrust, power, and pitch of props.

Ocean Fiber Optics

With the expanding need for electronic communication between distant parts of the world, fast and reliable internet and phone connections have become more essential than ever. Fiber optic cables are excellent for fast and reliable connections. They work much like a flexible plastic pipe stretching several miles long and filled with reflective mirrors. Electronic messages from one end of this “pipe” are reflected off these “mirrors” through its entire extent, and are clearly received no matter how much the pipe is bent or twisted along its length.

Working in collaboration with PetroCom, a leading cellular and satellite service provider in the Gulf of Mexico, GulfFiberNet$^{\text{TM}}$ is bringing to life their impressive goal of establishing a fiber optic cable system. It is intended to run from Fourchon, LA to Freeport, T\X, providing high speed, high bandwidth access to offshore infrastructures. When its construction is completed in 2005, the system will provide its customers with better reliability and security than ever before. The maintenance of this system relies on the regular checks and repair of underwater remotely operated vehicles. The second task of the MATE contest simulates one such repair of a damaged fiber optics connection.

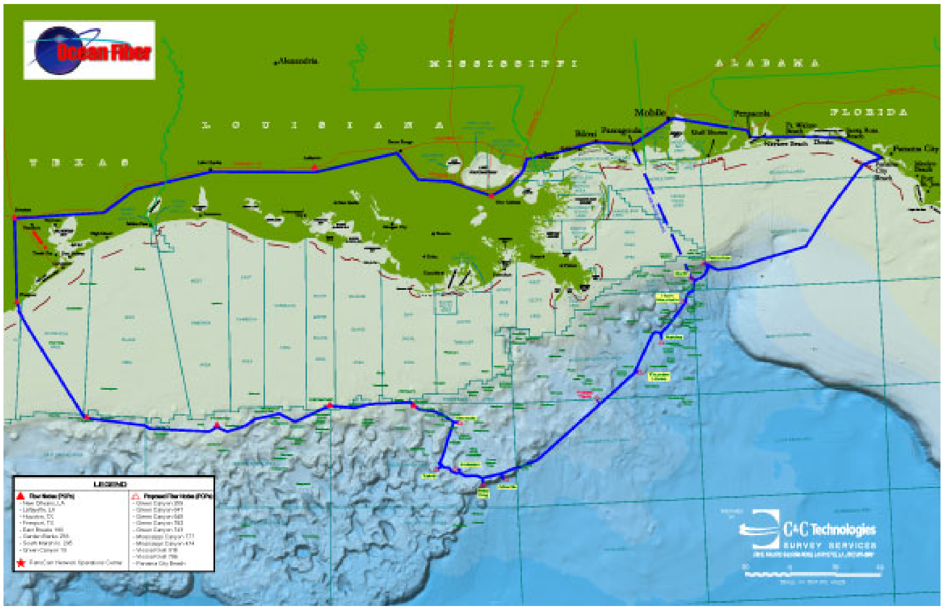


Fig.11: *An image taken from the GulfFiberNet website depicting the completed route of the fiber optic cable system.*

Ocean Design Inc., a manufacturer of underwater and harsh environment electronics and fiber optic systems, is another corporation that would benefit from a speedy fiber optic repair system. The company relies on a marketing strategy that heavily emphasizes the high dependability and reliability of their systems, making an efficient repair system absolutely necessary to maintaining their position as one of the leading providers in the world.

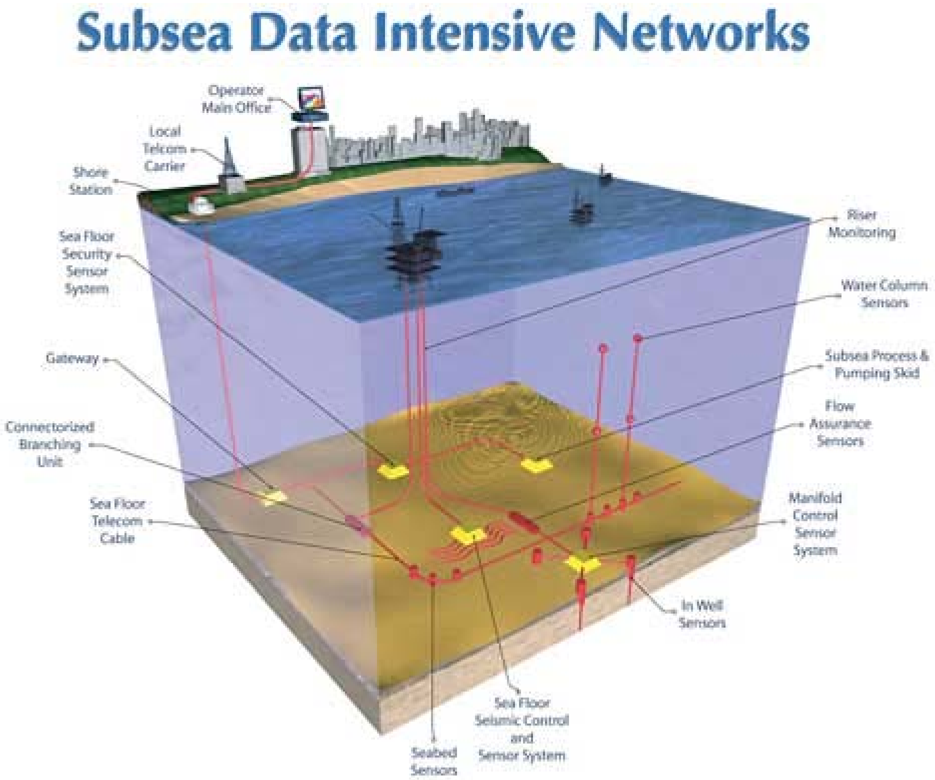


Fig.12: *A image of one of ODI's extensive fiber optic systems.*

RESOURCES:

- www.odi.com
- www.gulffibercorp.com/index.html
- www.howstuffworks.com/question402.htm

Acknowledgements

The TJ ROV Team would like to thank MATE for the opportunity to compete in the 2005 ROV Competition. In addition we thank the following people and organizations whose support made this project possible:

- Our sponsor – Mrs. Lisa Wu, Director of the Oceanography Technology Lab at Thomas Jefferson, for her encouragement and support.
- Our mentors – Mr. Justin Manley, an ocean engineer for MitreTek, and Mr. Ron Anderson, Director of the Robotics Technology Lab, for their invaluable advice and support.
- Mr. Rick Buxton, Director of the Prototyping Technology Lab, for the use of his equipment.
- Dr. Anthony Wu, Mr. Bradley Brown, and Mrs. Kathy Brown for their generosity with their time and talents and their practical advice.
- The Thomas Jefferson Technology Department, for its financial support.
- CarderRock Naval Research Center, for use of their submarine tanks and testing facilities.

The *Proletariat Torpedo* is so named because of its cost-efficiency – one of our goals – and to honor the fact that this competition is an affordable endeavor for almost anyone who wishes to participate.

Project Expenses

School Name: Thomas Jefferson High School for Science and Technology
Instructor/Sponsor: Mrs. Lisa Wu, TJHSST Oceanography Lab Director

KEY: purchased
donated

	Item	Method of Acquisition	Amount	Quantity	Total
Frame	1.27 cm PVC pipe	purchased by Oceanography	$1.50 / 3.048ft	~12.192 ft	$6
	light-weight sheeted plastic	purchased by Oceanography	$15	2	$30
	nut/washer	purchased by Oceanography	$1.50	10	$15
Control System	circuit board	donated by Robotics Lab	$4/sq ft	3 sq ft	$3
	IRF mosfet	donated by Robotics Lab	$2	4	$8
	wires	donated by Robotics Lab	$0.10/ft	2ft	$20
	double pull, double throw counter off switch	donated by Robotics Lab	$2.50	7	$17.50
	1 meg potentiometer	donated by Robotics Lab	$1.50	4	$6
Propulsion	500 GPH RULE bilge pump	donated by Robotics Lab		2	
	2000 GPH RULE bilge pump	purchased by Oceanography	$85.99	2	$172.00
	1.5" propeller	donated by Robotics Lab	$2.75	2	$5.50
	3.5" propeller	donated by Robotics Lab	$2.75	2	$5.50
Manipulation	ABS black sheet	donated by Robotics Lab	$3/sq ft	36 sq ft	$108
	solenoid	purchased by Oceanography	$7	2	$14.00
Vision	SeaView® camera	donated by TJ ROV 03-04	$135	2	$270
Ballast	Gatorade® bottles	donated by TJ students	$10/24 pack	24	$10
Tether	16 gage wires	donated by Jim Plasker	$0.39/ft	60ft	$23.40
	18 gage wires	donated by Jim Plasker	$.43/ft	120ft	$51.60
MISC	screws	donated by Lucas Brown, Rol	$0.10 ea.	30	$3
	12 V motorcycle battery	donated by Lisa Wu	$19.45	1	$19.45
	electrical tape	donated by Lucas Brown	$1.50	2	$3.00
	alligator clips	donated by Robotics Lab	$0.25	2	$0.50