Technical Report

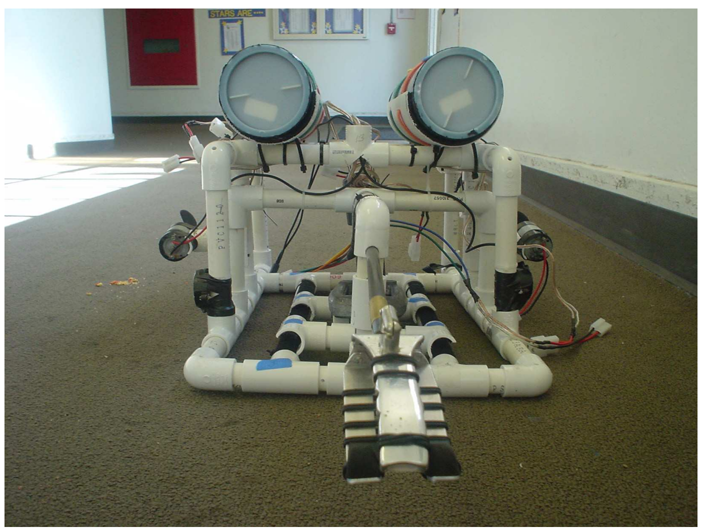
Submitted May 27, 2005

Science Club ROV Group

Richard P. Dana Middle School
13500 Aviation Blvd., Hawthorne, CA 90250

2005 MATE Center/MTS ROV Competition

June 17 – 19, 2005



Little Homer

Team Members

Syreeta Adams, John Arakaki, Michael Beck, Richard Beck, Mariam Chkadua, Nethanya Cortez, Joey Kaneda, Brent Scheneman

Teacher: **Douglas Foster**

Abstract

A Remote Operated Vehicle (ROV) is a mechanical device that is controlled by an outside source. The Dana School ROV team from Hawthorne, California was founded in the spring of 2004 with the intention of building an ROV to explore the underwater California Coast. The team built their ROV using PVC pipe, speaker wire, 6-12 VDC motors, flip switches, microphones, and a video camera. The ROV costs just over $300, has a robotic arm, and runs off a DC 12-volt battery. It is unknown how deep it will go, but we have tested it down to 7.6 meters in sea water. The ballast weights and buoys can be moved to adjust the center of gravity and center of buoyancy. Shortcomings include open frame motors and limited electronics. This ROV placed 2nd in the 2005 Southern California Regional ROV Fly-Off Competition at UC San Diego, qualifying it for the National MATE/MTS Competition at the NASA Neutral Buoyancy Lab in Houston, Texas.

<u>Table of Contents</u>

Introduction

A Remote Operated Vehicle (ROV) is a mechanical device that is controlled by an outside source. ROVs can be sent into dangerous areas where humans cannot venture, like the depths of the ocean and far out into space. There is nothing more practical, safe or cost efficient than an ROV to explore our world and the worlds around us.

Dimitri Rebikoff developed the first ROV, named POODLE, in 1953. Commercial firms saw the future of ROVs, advancing the technology to support offshore oil operations. The military has used ROVs for years to test for mines and search for terrorists. The police use them to detect and disarm bombs, and search houses and premises for any signs of danger. Today, marine ROVs are used for many purposes, such as repairing communication links, collecting and recovering samples, and hunting for sunken treasure.

The Dana ROV team started out as the electronics division of the after school Science Club. Our science teacher was interested in studying underwater animals and exploring the deep. We built a small ROV in class, and tried it out at Marina Del Rey, but it didn't move very well. So, we completely rebuilt it with new tethers and larger motors and it worked a lot better. We are proud to be competing in the 2005 MATE Center National Competition, and to take part in this once in a lifetime opportunity.

Mission Tasks

Our first task simulates capping a leaking oil well. Our mission is to turn an 80 cm length of PVC pipe (oil valve) 90 degrees to close the leak (See Figure 1). Since our ROV is fast and maneuverable, we can push the valve with the front of the ROV in a very short amount of time. The mission is actually supposed to take place in the Gulf of Mexico, so the water would have a lot more minerals in it than the clear water in the pool. At deeper depths, the water pressure gradually increases and visibility decreases.

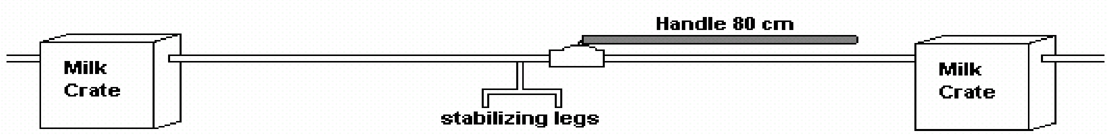


Figure 1. Task 1. Simulated leaking oil well made of PVC pipe and milk crates.

Figure 2. Task 2. PVC communications Probe.

Figure 3. Task 2. Simulated junction box with PVC open port on top.

The second task simulates repairing a fiber optic cable connection to re-establish a communications link. To fix the fiber optics cable, we must insert a communications probe into the open port of a junction box. (See Figures 2 and 3). The ROV must be able to drop a rod (1.27 cm diameter) into a tube (4 cm diameter).

The third task simulates installing an instrument module on the Hubble space telescope. We will attach a mock instrument package to a mock Hubble space telescope using Velcro as our attaching mechanism (see Figures 4 and 5). This test is not in space, but at Johnson Space Center Neutral Buoyancy Laboratory (N.B.L.) pool, and one must realize there are many differences between space and water. The main difference is that there is no air or water in space, so the ROV propellers would not have anything to push off of. It would just stay still and be useless. In order for it to move, it would need some other type of propulsion that would probably melt our PVC structure. Also, the ballast and floatation system, used to maintain stability in a water environment would be useless in a zero gravity situation.

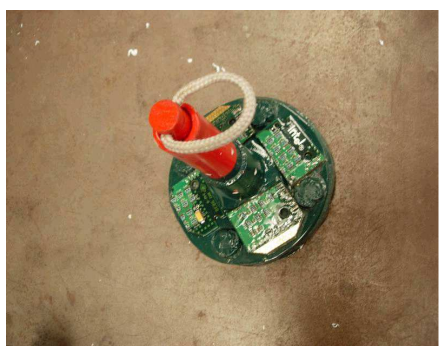


Figure 4. Task 3. Mock Instrument Package.

Figure 5. Task 3. Mock Hubble Space Telescope.

ROV Design and Rationale

When we began building our ROV, we looked at many different structures. We based our initial design on an ROV found in the book Build Your Own Underwater Robot by Harry Bohm and Vickie Jensen (1997). The major limiting factors for building our ROV were our lack of funds and the fact this is our first competition. We decided to design our ROV to be simple with a flexible design.

The structure of the ROV is a box-like form (46 cm X 32 cm X 21 cm) made of 12.7 mm diameter PVC (Polyvinyl Chloride) pipe and connectors (See Figures 6 and 7).

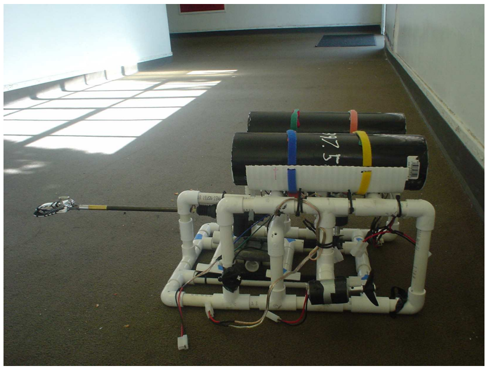


Figure 6. Side view of ROV.

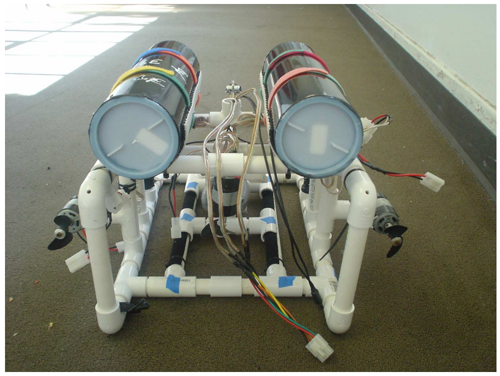


Figure 7 Rear view of ROV.

PVC was used to construct the ROV frame because it is lightweight (specific gravity 1.42), easy to work with, inexpensive, durable, and available at any hardware store. The relatively small size and mass help decrease drag, allowing the ROV to move faster, maneuver better, and use less powerful, inexpensive motors. Using PVC pipes and connectors allows for easy modifications and repairs, and makes it easier to add on accessories.

To achieve neutral buoyancy and maximize stability, we added a lead (specific gravity 11.34) ballast and ABS (Acrylonitrile-Butadiene-Styrene, specific gravity 1.02-1.17) sealed tube floats. The ballast is a 1.36 kg lead diving weight attached to the bottom of the ROV (See Figure 8) using strips of Velcro and the floats are attached to the top with Velcro straps. The floats are made of 76.2 mm diameter ABS tubing, sealed with ABS caps (See Figure 9). The floats are the only sealed containers on the ROV

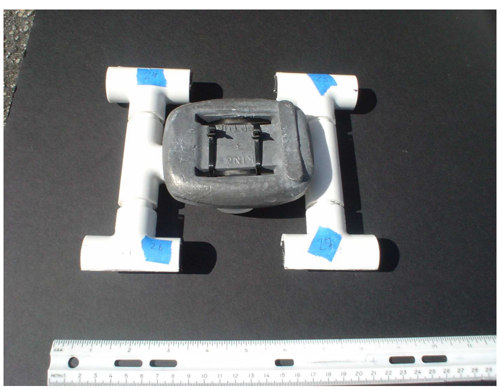


Figure 8 Lead weight ballast mounted on PVC frame.

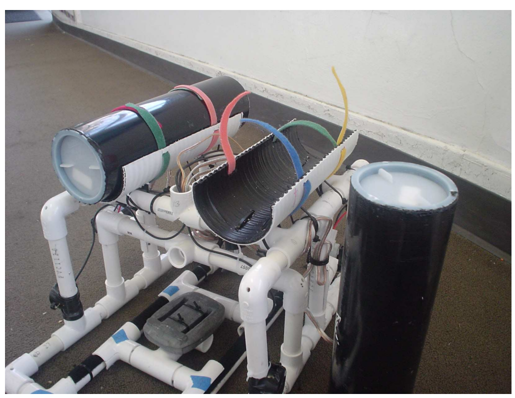


Figure 9. Adjustable ABS Tube Floats.

and sealed with plenty of ABS glue. Several ABS tubes were cut to different lengths to adjust the volume of the floats, while the lead ballast remained constant. The positions of the ballast and floats are easily adjusted to fine-tune the center of buoyancy above the center of gravity. This helps stabilize the ROV, keeping it upright and level. The ROV will rise or lower in the water using a single, reversible motor.

We used three reversible 6-12 V.D.C. motors (one center for up and down, and a motor on each side to move forward, backward, left, and right). Attached to each motor shaft is a two bladed 56 mm diameter propeller (See Figure 10). PVC mounts are used to attach the motors to the ROV frame and the motors can be easily replaced or adjusted to different positions or angles. The motors are wired to detachable wire harnesses, so they can be easily disconnected if they fail. The motors are not waterproof, and we expect them to eventually fail after repeated usage. The motors are inexpensive and we have plenty of back-ups to replace any damaged motors. We did not test any other propellers, but the ones we are using seem to work well.

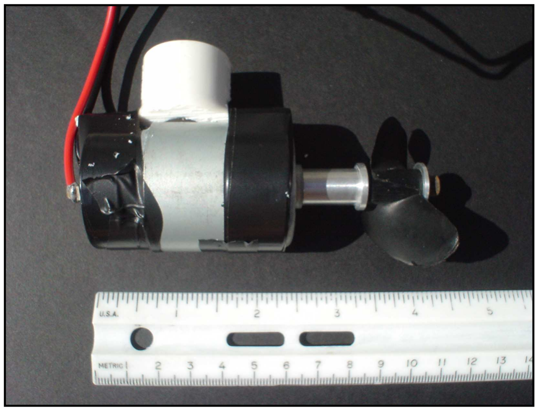


Figure 10. Motor, PVC motor mount and propeller.

There are fifteen wires in the tether, six for the motors (paired power and ground for each motor), two for the arm, four for the camera (power, ground, and two communication wires), and three for the microphones (left, right, and ground). The wires are enclosed in a polypropylene rope for protection and to keep them together (See Figure 11). Pipe insulator is attached to the tether at regular intervals to create neutral buoyancy (See Diagram 1). The tether length is 15.24 meters. We covered the end of the tether nearest the control box with plastic insulator tubing from Pep Boys.

We had originally made the ROV for underwater research on boat trips. The objectives were to look for things under the water and we thought it would be neat to hear things too. The camera on the ROV is a black and white waterproof camera that we purchased from Harbor Freight. The camera has eight infrared LED lights surrounding the lens to illuminate dark areas. The 0.91 kg weight that attaches to the bottom of the camera was not used. Our intention for the National competition is to have a second ROV equipped with a second camera to aid with the second and third missions.

We have a pair of piezo crystal microphones, which are small, lightweight, and do not use a power source because they convert sound energy directly into electrical energy. A microphone is mounted to each side of the ROV to create a stereo effect.

The control box is made from 5mm Plexiglass. Inside is a circuit for contolling motor speed. We built the joystick so we could control the three motors with one hand, so the other hand is free to work the variable speed control. The joystick is made of PVC, and motor activation and direction are controlled by DPDT (double pull, double throw) momentary, center off switches. A four-fuse block is used to protect our electronics. To keep things simple, the electronics on our ROV were minimal. We did not use any relays, integrated circuits, or transistors other than what is on the variable speed control. We used a sealed 12-volt battery to test the ROV and all of its accessories.

We began to look more at the competition and its tasks and saw that we needed some type of grabbing device. We looked at some toy grabbing devices and decided on a simple opening and closing claw. The claw was made of a tent pole, some copper wire, two aluminum pieces for claws, PVC pipe, and an actuator motor (see Figure 11). We have three different arms for our ROV that we can swap out in a matter of seconds.

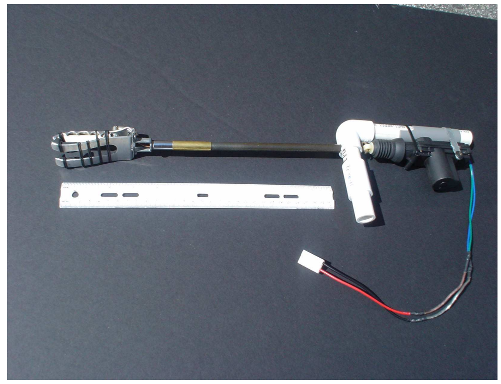


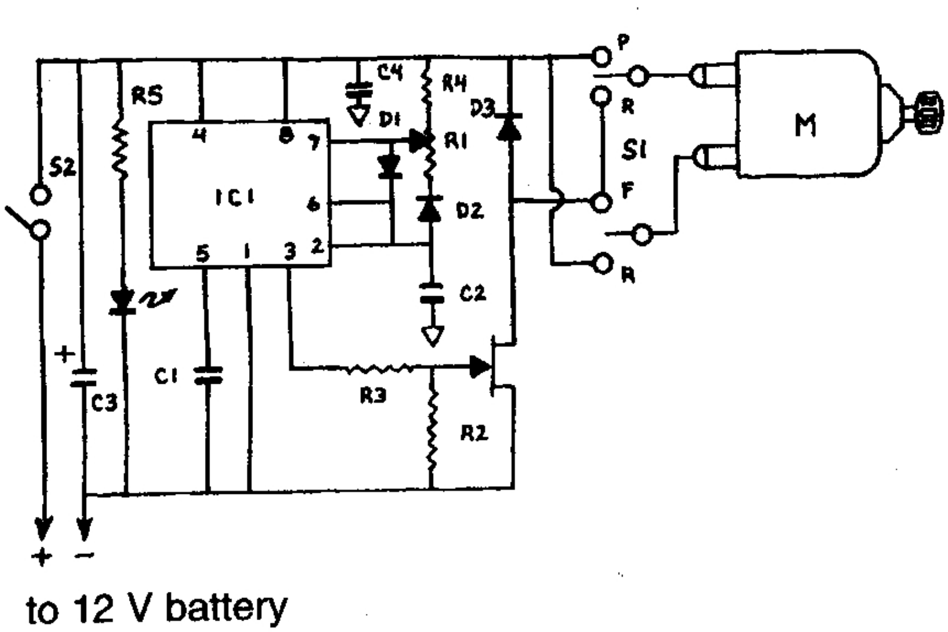
Figure 11. Mechanical arm with actuator motor.

For the second task, we will use a rod attached to the ROV. The communications probe is held onto the end of the rod using friction. The ROV will maneuver into position and insert the probe into the open port. The ROV will then reverse direction and slide the probe off the rod. We have two different arms for the third task and we are testing which arm works best.

Our ROV is made of mostly environmentally safe materials. There is no battery on board, so there is no chance of a HCL acid leak. The PVC frame and ABS float tanks of our ROV are insoluble in water and harmless to creatures of the sea. However, our ballast and solder is made of lead, which is poisonous. The solvent that holds our floatation caps to the floats is probably toxic and parts inside the motors may be potentially harmful.

Electrical Systems

We conducted our test with a 12V Lead Acid battery. The 12V battery first feeds a motor speed control circuit and then it goes to a fuse block that holds four fuses. The speed control circuit was bought as a kit and is built around a 555 Timer. After the current leaves the fuse block, the current then goes on to two DPDT momentary paddle switches which are located at the bottom of the joystick, and one DPDT rocker center position off switch which is located at the top of the joystick. Then after the switches, the current then goes through 15.2 meters of 16 gauge speaker wire, and then to the three 12V motors. The resistance of the wires going to the motors are as follows: first pair 1.4 ohms and 1.9 ohms, second pair 1.2 ohms and 1.3 ohms, third pair 1.4 ohms and 1.4 ohms, and the fourth pair which goes to the robotic arm, 1.6 ohms and 1.9 ohms. Because of the resistance of the wire, the voltage at the motor was lower than the voltage at the battery. The 12V battery also provides power to the robotic arm and the underwater camera that is connected to a monitor at the surface. The camera that we are using can go to the maximum depth of 18.6 meters. This camera can work in 0 LUX of illumination. We are experimenting with different cameras. Also on the ROV, we have two piezo electric crystals which act as microphones. These microphones do not need power, because the crystals convert sound energy into electrical energy.



Schematic of
Motor Speed Control Circuit

Motor Speed Control Circuit Parts

Resistors

Ra1 Pot
R2 20K
R3 1K
R4 1K
R5 470 ohm

Capacitor

C1, C4 O.3uf 25 v
C2 0.082
C3 100uf

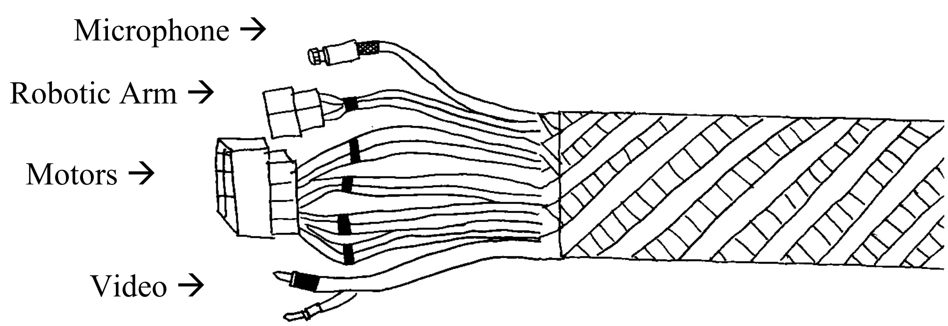
Diodes

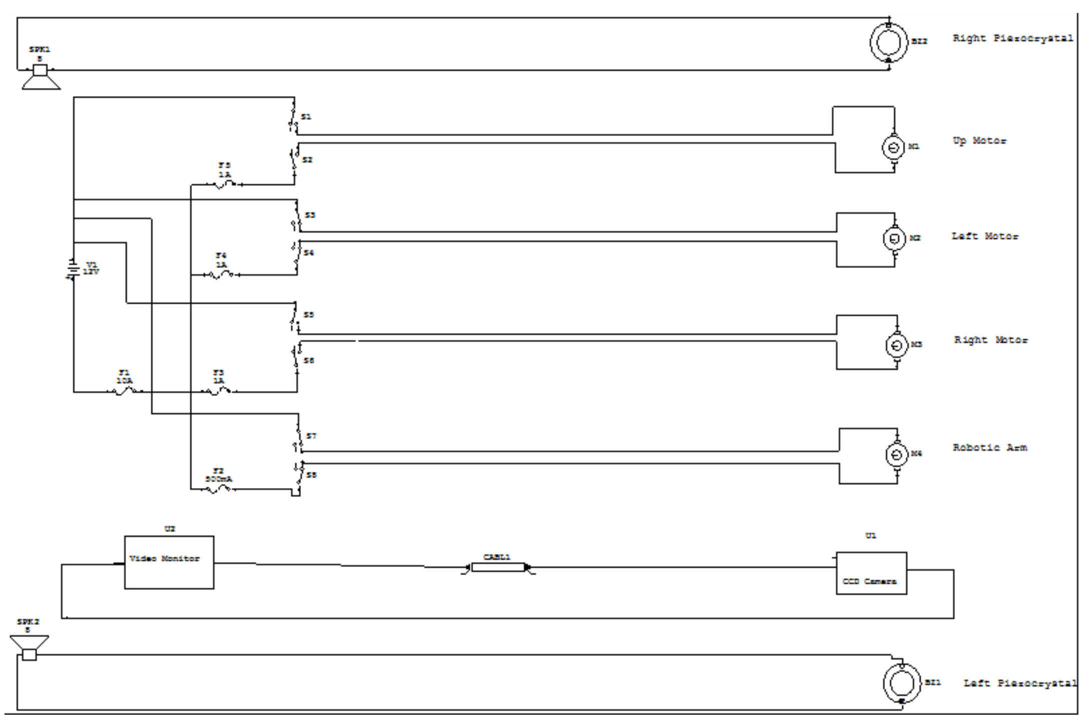
D1, D2 Signal Diode
D3 3A-300V (large) (MR504)

Miscellaneous

Q1 Power Mosfet
IC1 555 (1455P1 or 035B)
S1 Switch
S2 Switch
M Motor
LED
Heat Sink
PC Board
Hardware & Wire

Diagram 1. Pictorial Diagram of Tether





Controller Schematics

Budget/Expense Sheet

ROV Budget/ Expense Sheet

	Item	Description	Price/unit	Qty	Extended price	Sources
Structure						
	PVC 8 mm inner diameter pipe	Polyvinyl chloride straight tube (length 3.05 m)	$1.39	1	$1.39	Home Depot
	PVC three way connectors	PVC T connector	$0.18	30	$5.28	Lowe's Hardware
	PVC elbow	PVC right angle connector	$0.14	12	$1.73	Lowe's Hardware
	PVC two way connector	PVC straight connector	$0.14	2	$0.28	Lowe's Hardware
	PVC four way connector	PVC cross connectors	$0.58	2	$1.16	Lowe's Hardware
	wire connector	2 Conductor (CON-20)	$1.20	4	$4.80	NGST Swap meet
Propulsion						
	D.C motors	6-12 VDC motor	$3.00	3	$9.00	All Electronics
	Propellers	56mm diameter, 2 bladed	$2.75	3	$8.25	Precision Engineering
	Propeller Coupler	Attaches propeller to motor	$8.00	3	$24.00	Hobby People
Floats						
	Float tube	75 mm inner diameter ABS pipe	$1.13	2	$2.25	Home Depot
	Float caps	ABS plug test cap	$0.65	4	$2.60	Home Depot
Ballast						
	Ballast/Weight	1.35 kg lead diving weight	$3.00	1	$3.00	Dive and Surf
Tether						
	1.27 cm x 15.2 m Braided Poly Rope	Polypropylene rope	$4.99	1	$4.99	Big Lots
	16 gauge speaker wire	Copper Speaker Wire 15.2 m	$0.39	15.2	$5.93	Home Depot
	24-Gauge Audio Cable (278-513)	Copper Speaker Wire 15.2 m	$8.79	1	$8.79	RadioShack
	Video cable	Video cable (CB-54)	$0.51	15.2	$7.75	All Electronics
	wire conduit	plastic wire holder	$3.29	1	$3.29	Pepboys
Audio video equipment						
	Phono jack	Solder-Type Stereo In-line jack (274-274) 2 pk	$3.99/2	1	$2.00	Radio Shack
	Video camera	Video Camera, monitor, battery, and cable	$110.00	1	$110.00	Harbor Freight
	Microphones	Piezo crystal microphone	$0.75	2	$1.50	NGST Swap meet
Arm						
	Actuator motor	Car door lock actuator motor	$5.00	1	$5.00	All Electronics
	Arm	Fiber glass tent pole	$1.00	1	$1.00	Mr. Chkadua
	Aluminum claw	Aluminum grasping device: homemade	$1.00	1	$1.00	Mr. Chkadua
OLD Control box						
	Control Box	Black plastic control box (270-1806)	$4.99	1	$4.99	Radio Shack
	Toggle switches	DPDT Momentary, center off switch (275-709)	$4.49	4	$17.96	Radio Shack
	Fuses	Glass fuses 10 amp	2.49	1	$2.49	Radio Shack
	Banana Plugs	Connector for battery (2 pack)	$5.96	1	$5.96	Home Depot
	In Line Fuse Holder	Fuse Holder near power source	$2.29	1	$2.29	Radio Shack

Miscellaneous						
	Velcro straps	Holds Floats to ROV	$0.60	8	$4.80	Home Depot
	Velcro tape	Roll of Velcro tape	$6.96	1	$6.96	Home Depot
	Wire tie	Holds wires together 100 pack 10.16 cm	$1.25	1	$1.25	NGST Swap meet
	Wire tie	Holds wires together 100 pack 30.48 cm	$2.50	1	$2.50	NGST Swap meet
	Wire tie	Holds wires together 100 pack 20.32 cm	$1.67	1	$1.67	NGST Swap meet
	Electrical tape	Electrical tape	$0.50	1	$0.50	99 Cent Store
	Solder	Solder for connecting wires and switches .45 kg	$8.76	1	$8.76	Home Depot
	Hot glue	Hot glue	$0.99	1	$0.99	Home Depot
	Silicone cement	Silicone cement 82.81 mL	$6.99	1	$6.99	Petco
	Shrink wrap	Covers exposed wires	$1.00	1	$1.00	NGST Swap meet
	ABS Glue	Adhesive for float caps to float tubes	$7.87	1	$7.87	Home Depot
				Total Cost of old ROV	$291.97	
NEW Control box						
	Control Box material	5mm plexiglass	$2.00/2.2 kg	4.4 kg	$4.00	Souh Bay Plastics
	Toggle switches	DPDT Momentary, center off switch (275-709)	$4.49	2	$8.98	Radio Shack
	Rocker switch	Rocker Switch (GC 35-3525)	$10.00	1	$10.00	Torrance Electronics
	Variable speed control kit	Controls speed of propellers (MSC-6)	$15.00	1	$15.00	All Eletronics
	Fuses	Glass fuses	$2.49/4	4	$2.49	Radio shack
	Banana Plugs	Connector for battery	$5.96/2	2	$5.96	Home Depot
	In Line Fuse Holder	Fuse Holder near power source	$2.29	1	$2.29	Radio Shack
	Multi-Pin Connectors	Allows control box parts to be disconnected				
		2 Conductor (CON-20)	$1.20	4	$4.80	All Electronics
		4 Conductor (CON-40)	$1.90	5	$9.50	All Electronics
		6 Conductor(CON-60)	$2.25	2	$4.50	All Electronics
				Total Cost of New Control Box	$63.52	
				Total Cost of New ROV	$321.80	

Challenges

Throughout the process of building our ROV, we were challenged to solve many problems. Fortunately, we have a team that is highly motivated and very focused. The first time we tested our prototype, we were on the UCLA Sea World boat. The wires in the tether were held together with wire ties and not enclosed in the polypropylene we are using now. There was no camera so we could not see underwater. The only things on our ROV were the motors and the buoy pieces. This ROV did not have an appropriate ballast and floatation system, and was positively buoyant, so it could only float on the surface.

The first challenge to overcome was to create neutral buoyancy and stability. When we tried to send our prototype underwater, it sank. When we tried to raise it up to the surface, our ROV flipped over, end over end. So we decided to change our robot's structure. We used Archimedes' Principle which says that the buoyant force of an object is equal to the weight of the fluid displaced by that object. We changed the top of the robot to add two floats. Since these floats are hollow more water is displaced to achieve neutral buoyancy and maintain an upright position. We added a ballast system (a 1.35 kg lead diving weight) to the bottom of the ROV. One advantage of our ballast and floatation system, is that we can easily reposition them in order to adjust the center of gravity and center of buoyancy. This allowed us to fine-tune the system so that the ROV would stay level in the water.

The actuator motor in the arm of our ROV burned out because the mechanism would not close all the way when the jaws were holding something. The actuator held its position too long and the 1.2 amp current blew out the motor. When the motor is running there is a magnetic field, and a current is running through the motor creating a back electromotive force. When the motor is prevented from turning, the current is still running, and eventually burns the wires.

The original floats were made of neoprene insulators for pipes, but they were not very effective. Then we tried styrene gutter pipes, but when we glued the tubes to the caps we used PVC glue, and it melted the PVC caps, causing them to leak. We fixed the problem by using new floats made of ABS tubing, ABS caps, and Lo-Voc ABS glue.

While we were at the competition in San Diego, we were having problems with the speed controller. We used the aluminum (good conductor) bleachers as a workbench. The back of the speed controller was bare, so when we turned it on, the electricity ran through the copper and the aluminum, causing smoke to rise. Next time we will bring cardboard mats.

Overall, we have accomplished a lot working together, and have learned something new from each and every challenge. Fixing the problems has been an exciting and rewarding experience for all of us.

Troubleshooting Techniques

After competing in San Diego for two days, we all decided to make a second ROV. We just had to make modifications to the first one. The first original ROV that we built, named Little Homer, had a lot of problems with floatation. We figured out that one of our floats was filling up with water, which added more weight to the ROV and made it even more difficult to move around. We replaced the styrene floats with ABS floats and the ABS glue did not dissolve the ABS floats.

Another problem we encountered was when all three motors stopped working. First, we checked the battery voltage. The battery was okay, so then we tested the continuity of the fuse at the battery. We found out that the inline battery fuse was okay. Next, we checked continuity of the fuses in the control box, but found out that they were okay, too. So then we checked to see if the motors were working and found that they were fine as well. We checked to see if all the connectors were connected and found out that one of the connectors was not plugged in. So from now on, we will check all the connectors first.

In the competition, we accidentally blew out a fuse by holding the switch for the arm too long. We identified the problem by using the digital multimeter to buzz out the fuse to see if it worked. We discovered that the fuse had blown.

Lessons Learned

While constructing our ROV we learned many things. Two lessons we learned were the importance of stability and simplicity. Our first ROV lacked a ballast and floatation system and was negatively buoyant (it would sink). When the motor was turned on to bring the ROV to the surface, it would tip forward. Controlling the ROV was very difficult and it was obvious we needed a new design.

We built our second ROV larger and with a simple ballast and floatation system. We placed a 1.35 kg weight on the bottom and two ABS floats on the top. We adjusted the size of the floats to achieve neutral buoyancy. We adjusted the position of the ballast and floats to place the center of buoyancy directly above the center of gravity to keep our ROV upright and level. This increased the stability of our ROV and gave more control.

We made a very complicated control box using many relays, connections, wires, and a video game joystick. When we tried to use this box, our ROV moved only in reverse and only turned right. We could not get the ROV to move forward or turn left. We tried to fix the box in time for our regional competition in San Diego but we could not trace the problem due to the complexity and our limited understanding of electronics. We decided to use our previously built, simple control box although it was more difficult to work with. The simple control box ,however worked well enough in the competition to earn us second place. We decided simple works best. Using simplicity is sometimes referred to as the Law of Parsimony or the K.I.S.S. (Keep It Simple Stupid) principle.

Future Improvements

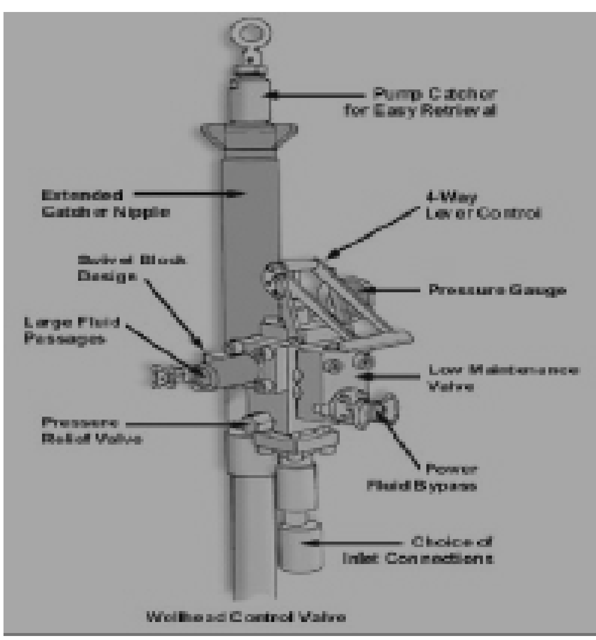
If the Dana ROV Team had more time and resources, the following improvements could have been accomplished. Another, separate ROV with its own tether and control box would have aided us in the second task by giving us a picture to work with. Another way we could have improved our ROV, is by creating a ballast system with pumps to control Little Homer's density instead of being neutrally buoyant and using motors to move up or down. This way, we wouldn't have to worry about our up/down motors rusting and rendering our ROV immobile when it comes to depth in the water. Instead of using a motor in our arm mechanism, we could have replaced it with a durable solenoid capable of withstanding high currents. This way, we wouldn't have to worry that the actuator motor in the arm would burn out. Also, we could have made protectors for Little Homer's motors so the wires would not become tangled up in the rotors. We feel that it would be more efficient to have the fuses more accessible. An Amp Meter mounted on the control box would give us warning if a fuse were about to blow.

Career Possibilities

A career that is relevant to the first task of the Ranger class is a wellhead pumper. A wellhead pumper is trained in the methods of capping an oil well. Quoting from the Occupational Information Network, some job duties a wellhead pumper performs are:

- Monitor control panels during pumping operations in order to ensure that materials are being pumped at the correct pressure, density, rate, and concentration.
- Operate engines and pumps in order to shut off wells according to production schedules, and to switch flow of oil into storage tanks.
- Perform routine maintenance on vehicles and equipment.
- Repair gas and oil meters and gauges.
- Unload and assemble pipes and pumping equipment, using hand tools.
- Attach pumps and hoses to wellheads.
- Start compressor engines, and divert oil from storage tanks into compressor units and auxiliary equipment in order to recover natural gas from oil.
- Open valves to return compressed gas to bottoms of specified wells in order to pressurize them and force oil to surface.
- Supervise oil pumpers and other workers engaged in producing oil from wells.
- Drive trucks in order to transport high-pressure pumping equipment, and chemicals, fluids, or gases to be pumped into wells.[1]

A wellhead valve is used to isolate the flow of oil or gas at the takeoff from an oil or gas well. The design is usually a plug or gate valve. An example of a wellhead pumper's control valve is shown below:



Wellhead Control Valve

Acknowledgements

The ROV Team has accomplished a great deal in this last year. However, this may not have been accomplished without the support and assistance from many different sources. With this in mind, the Dana ROV club would like to thank the following:

Mr. Foster, our mentor and science teacher for starting this team and teaching us how to work together along with many other things such as building a robot and how they work.

Ms. Pamelyn Spriggs for assisting us with the picture taking, typing and arrangements.

Ms. Aileen Harbeck for helping us with our report.

Mr. Benjamin Ear, a Raytheon engineer who so graciously gave his personal time to assist us and teaching us about electronic components.

Mr. Chkadua for helping us construct the prototype robotic arm.

Principal Matt Wunder and the Dana School Staff for supporting our efforts and allowing us to stay late to do our work.

Alberto Edeza for helping us with buoyancy.

Hawthorne pool and its entire staff for letting us come every Friday night to test our ROV.

Northrup Grumman for helping us with travel costs.

TOPS (Teachers and Occidental in Partnership = Science) for providing funding for our science club field trips.

MATE (Marine Advanced Technology Education) Center

MTS (Marine Technology Society)

Johnson Space Center Neutral Buoyancy Lab

Mr. Foster would like to thank the Cabrillo Beach Aquarium for sponsoring his attendance at the MATE 2003 ROV Workshop.

And finally, all of the parents of the ROV team members for being so supportive and encouraging.

References

Bohm, Harry and Jensen, Vickie. Build Your Own Underwater Robot. Vancouver, B.C., State: Westcoast Words, 1997.

A Brief History of ROVS. rov.org. Remotely Operateld Vehicle Committee of the Marine Technology Society. 7 May 2005. <http://www.rov.org/educational/pages/history.html>.

The Fleet Type Submarine - Chapter 5. maritime.org. 27 Dec. 2001. Maritime Park Association. 7 May 2005. <http://www.maritime.org/fleetsub/chap5.htm>.

How to Build Your Own Underwater Robot and Other Wet Projects written by: Harry Bohm and Vickie Jensen. Pub. by Harry Bohm

Prentice Hall Science Explorer: Focus on Physical Science written by: David V. Frank, Peter Kahan, John G. Little, Steve Miller, Jay M. Pasachoff, and Camille L. Wainwright.
Pub. by Prentice Hall Inc. C.2001 Prentice Hall Inc.

Marine Advanced Technology Education, 2005
http://www.marinetech.org/rov_competition/index/php

Material Safety Data Sheet - ABS. 1 Jun. 2003. Polymer Technology & Services. LLC. 21 May 2005. <http://www.ptsllc.com/absmds.html>.

Material Safety Data Sheet - Lead. Teck Cominco Metals LTD. Vancouver, British Columbia. 15 Dec. 2003.

Material Safety Data Sheep - PVC pipe. North American Pipe Corporation, Westlake Group of Companies. Houston, Texas. 26 Feb 2002

McCue, Gary. John Phillip Holland and His Submarines. The John Holland Project. 12 Jan. 2000. Computer Sciences Corporation. 24 May 2005 <http://www.geocities.com/gwmccue/Systems/Ballast_System.htm?20057>.

ROV Background. rov.org. Remotely Operateld Vehicle Committee of the Marine Technology Society. 7 May 2005. <http://www.rov.org/info.cfm>.

Summary Report for: 53-7073.00 - Wellhead Pumpers, O-Net Online, 2004
http://online.onetcenter.org/link/summary/53-7073.00

Weatherford Drilling and Well Services, 2003
http://www.weatherford.com/weatherford/groups/public/documents/artificiallift/hl_wellheadcontrolvalves/hcsp

World Book Encyclopedia Vol. M 13 1987 Edition pg.360 Metric System