The Manhattan Project

Mission College Preparatory Robotics Team

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Abstract

The *Manhattan* was designed, built, and operated by the Mission College Prep High School Robotics Team of San Luis Obispo, California. Over the course of the 2008-2009 school year, the team worked together to produce an innovative, quick, and robust ROV that could complete the submarine rescue mission tasks of the 2009 International ROV Competition, coordinated by the Marine Advanced Technology Education Center (MATE).

The ROV was named the *Manhattan* after a team member noticed the similarity between our control box and the nuclear codes briefcase. Thus, the events of this year became known as *The Manhattan Project*.

A detailed design rationale explains our multi-functional payload tools, motor and video systems. Schematic diagrams of electrical and pneumatic systems are presented. Our experiences in planning and practice are related to recent developments in the field of submarine rescue technology with respect to ROVs. Personal reflections of the team, lessons we learned and the challenges we overcame this year, our trouble-shooting techniques, and plans for future improvements to the ROV are discussed. Finally, a summary of our expenditures and incomes, an acknowledgment of the generous donors who made our work possible, and a references list are included.

Design Rationale

Overview and Philosophy

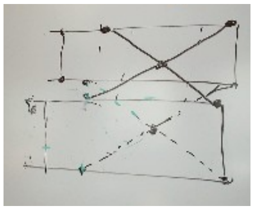


Fig. 1: A drawing of our ROV's frame design, sketched early in the competition season.

In building this year's ROV, we had several goals in mind for how the robot should turn out. First and foremost, we wanted the ROV to be lightweight in construction, which would aid in its maneuverability underwater. This lead us to use an aluminum frame with a similar design to last year's ROV in terms of motor placement. Other goals for the year included a tether which could detach from the control box, cameras that actually stay waterproof, and multipurpose, complex tools. We accomplished all of these goals.

Fig. 2: David Lundberg constructs the original ROV frame.

Early on, a hardware-only approach was selected. Our lack of programming knowledge and the ease of hardware wiring were the two primary factors in this decision.

Frame

The ROV frame is made of aluminum L-bar. Most of the aluminum on the ROV is 0.318cm thick which provides structural strength and support on the ROV. Aluminum is lighter weight than PVC, providing the ROV with greater agility and maneuverability. Additionally, aluminum makes it easy to attach any type of tool or structure while still providing the support needed to hold motors and cameras. Aluminum is also very forgiving; it can be riveted, drilled, cut, and bent, and it still provides proper support and stability.

Fig. 3: An early version of the ROV included no tail.

The frame is compact, though built slightly taller than strictly necessary for motor clearance, to allow extra room for tool installation. The ROV frame is in the shape of a short box, which allows the team to install tools in various places on the perimeter and which creates an open space in the middle to place cameras and motors. (See Figure 1 for a basic drawing of the design.) The basic frame is 50cm long by 20cm wide by 21cm tall; this small size keeps the ROV lightweight but is structurally sound to attach our tools to. See Appendix A for a SolidWorks drawing of the frame.

Fig. 4: The finished frame, with the cross-pieces visible.

The robot has two X-shaped crosspieces across the top and bottom. These provides support to the ROV as well as locations for mounting the sideways motor and transfer skirt. (See Figure 2.) The aluminum crosspieces do not impede the vertical motors' water flow. Two 6.5cm wide Lexan shields provide ample protection for the outboard horizontal motors and propellers on the sides of the frame. The Lexan strips were heated and formed into semi-circles, then bolted to the frame.

The frame was assembled using 10-24 zinc-galvanized steel hardware. The team found that using just one size of hardware saves time and simplifies finding nuts, bolts and washers that fit together, and reduces the amount of hardware storage necessary. (See Figure 3.) In seawater, the aluminum and zinc galvanized steel would corrode.

However, in the clean pools used for the ROV competition, corrosion is much less likely to occur than in seawater. After about 20 hours in the water, our ROV shows little evidence of aluminum-zinc galvanic corrosion.

Zinc-galvanized steel hardware cloth wraps the front, bottom, and back of the ROV to provide protection for the motors, tools, and cameras. The hardware cloth's edges are covered with strips of clear plastic tubing to provide protection from snagging the sharp edges. Two semi-circular pieces of hardware cloth are used at the rear of the Lexan side shields to prevent materials from fouling the side motor propellers.

The ROV has a piece of aluminum L-bar rising 35cm from the top back edge of the frame. This riser allows us to firmly connect the tether to the ROV to prevent stress and strain on the wiring and provides an additional camera mount looking down at the transfer skirt. (See Figure 4 on previous page.)

Video System

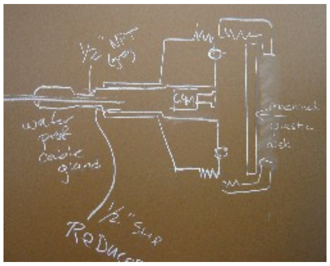


Fig. 5: The design of our waterproof housings proved sufficient all season long.

There are three cameras on our ROV. We salvaged one Harbor-Freight camera from last year's ROV. That camera got wet at 7 feet deep even though it was guaranteed to be waterproof at 60 feet deep in its commercial housing. Our second and third cameras are inexpensive color security cameras, trimmed to fit in new watertight housings. See Appendix B for camera specifications.

With the help of Scott Frazer at Long Beach City College, we designed and built waterproof PVC housings for our cameras. (See Figure 5 for this design.) The housings are made of PVC unions and adapters, and use Lexan windows to create a sealed front. Liquid-Tight cord seals keep water out at the cord end. The cameras are designed so that we can open up the front and maintain or replace the cameras without having to replace the cords and tether.

Fig. 6: The quad-splitter allows us to view all three cameras on a single TV at once.

Each camera is strategically positioned on the ROV: one camera gives a left forward view including the first pneumatic claw, another gives a right forward view and the second claw and a third color camera looks straight down upon the transfer skirt. All video inputs are fed to a quad splitter and into a single TV, providing a flexible means to view any or all cameras.

Last year, we also had serious problems caused by voltage drop and video fading, but this year the quad-splitter and using larger supply wiring to the control systems have helped to maintain high quality video throughput. (See Figure 6 for the quad-splitter.) Our camera housings are rather big. Their relatively large size causes some difficulty in visibility angles and positioning. Overall, we have done our best with the cameras and have run a successful video system this year.

The Tools: Claws and Transfer Skirt

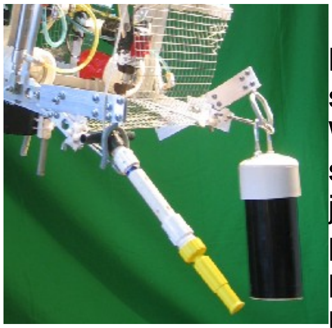


Fig. 7: Our two pneumatic claws hold the airline and ELSS pods.

Before designing tools, we built a mock-up of the competition submarine, in order to understand exactly what the tasks were. We brainstormed a variety of ideas, then started with the simplest designs. Originally, we had just two metal prongs jutting out of the robot, which would have been used to pick up pods. We replaced these with a prototype of the transfer skirt, a pneumatic claw, and a pneumatic lever. The lever was the most advanced tool we had ever built, but in the water it proved unreliable and difficult to use, and was replaced with the second claw, which was more reliable. (See Figure 7 for our two pneumatics claws.)

We ended up with three tools on our robot: a left pneumatic claw, a right pneumatic claw, and the transfer skirt. Each tool is lightweight, and can be easily detached and moved around the robot to wherever it will be most useful. Each tool is also multi-purpose; it can be used for at least two things.

Fig. 8: The pneumatic cylinder drives this lightweight arm.

Our two primary tools are both pneumatic claws. A pneumatic cylinder operates each lightweight aluminum arm which has two prongs extending downward that fit over the tongue. (See Figure 8.) They are primarily used to pick up and move the ELSS pods. Once a pod has been hooked through the U-ring, the two prongs are closed down over the tongue, securing the pod tightly so it cannot fall off. Second, they can be used to push, pull, or grab the hatch, the airline, the air valve, or anything else.

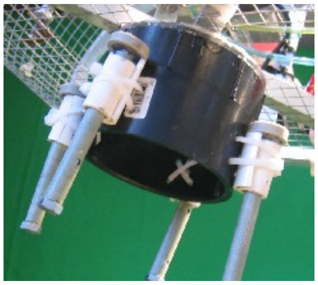


Fig. 9: Our transfer skirt.

The third tool is the transfer skirt. The transfer skirt is 10cm tall by 11cm internal diameter black ABS pipe mounted on the bottom of the ROV with four extendable prongs and a clear Lexan top, which allows us to see into the transfer canal. (See Figure 9 for this tool.) When the robot mates with the submarine, the prongs are pushed upward into the robot, so that they are not in the way. When not mating, the prongs fall back down into place, and are also used to turn the hatch on the submarine.

Each tool is lightweight, easy to mount to the frame, easy to operate, and can serve multiple uses.

Pneumatics

We chose to use pneumatic cylinders for our tool operators instead of solenoids or a gearbox to keep our design simple and easy to build. We use double-actuating pneumatic cylinders to provide sure and positive action for the claws. Since the cylinders do not rely on springs, they do not open unexpectedly.

Fig. 10: The pneumatic switch box.

Our pneumatic source is a 14,478.9 kPa scuba air tank. The tank regulator regulates the air coming out to 689.4 kPa. Because this pressure is too high for the competition, we use a secondary regulator to regulate the air to 40 PSI or 275.8 kPa.

Regulated air travels into the control box, and is split at a T-connector to the two electric Festo valves. Each valve controls one of the claws on the ROV, which are actuated by a toggle switch on the pneumatic switch box. (See Figure 10 for the pneumatic switch box.) The air flows from a valve down two pneumatic tubing lines (rated at 1206.6), through the tether and a pneumatic cylinder.

Propulsion

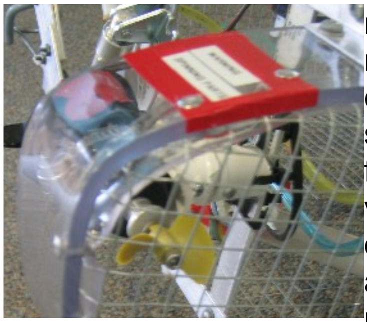


Fig. 11: A view of one side motor and its protection.

Our simple and lightweight propulsion system consists of five motors: three mounted in the horizontal plane and two mounted in a vertical plane. Each motor is a bilge-pump cartridge with a propeller mounted using a shaft collar and set screw. We use two different sized motors, 1890 liters per hour for the horizontal motors and 2840 liters per hour for the vertical motors, with different propellers depending on which direction the motor is mounted. We performed thrust and amperage testing using many combinations of size and propellers. See Appendix C for motor and propeller testing data.

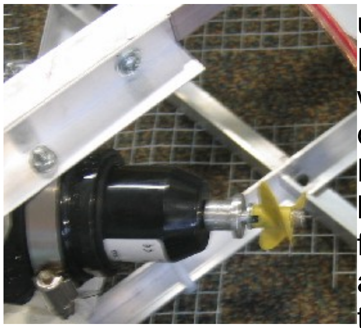


Fig. 12: A top-down view of the lateral motor.

Two of the horizontal motors are mounted to the frame sides using a cut PVC joint with a pipe clamp and zip ties. (See Figure 11 for a view of the side motor.) These motor mounts will be replaced with new hard plastic motor mounts. The design for this new motor mount can be found in Appendix D. Each motor is protected by a molded Lexan shield, which is bolted to the frame. These motors are placed outboard on the frame, which is a design which we used for the last two years, and which we choose for the extra torque it provides in turning the ROV.

The third horizontal motor is mounted centrally in the frame. This motor is set at a right angle to the first two horizontal motors to allow for lateral movement during the inspection of the submarine. This motor was added for extra maneuverability during the survey. (See Figure 12 for a view of this motor.)

The two vertical motors are mounted inside the frame using flat-bar aluminum bolted to the top of the motor and the rectangular top frame. We chose to use the more powerful motors in this configuration because it gave us the extra lifting power needed for the robot to easily handle heavy payloads.

Each motor is controlled by a double-pole, double-throw switch. These switches allow us to reverse the direction of each motor independently. This gives us a great deal of freedom for pitching or rotating the ROV, which is especially advantageous when picking up a dropped object or when positioned in an awkward orientation.

Control Box

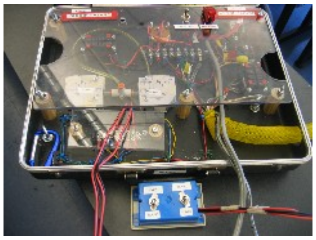


Fig 13: The control box and pneumatic switch box are shown.

Our control system was built in a vintage hard-backed briefcase with the dual goals of being self-contained and simple to operate. To this end, we used much of the same hardware design as last year, including a master kill switch (with an indicator light) that feeds the power to a fuse block, which acts as our main power distribution source. From the fuse block, power is distributed to each motor, to the pneumatics switches, and to the video system. A ground bus is used to provide ample attachment points for all devices. Overall, the control box consists of a central unit with power distribution and two separate control units for the pneumatics and motors. (See Figure 13 for the control box and pneumatics switch box.)

The motor control switches are located in an external project box wired directly to the control case, and which can be placed within the briefcase when the system is stored. The external motor box was built with the pilot's needs in focus, with the switches oriented on two perpendicular planes, so that only one pilot is needed for all five motors. Each motor switch is a double-pole, double-throw, momentary-on, center-off switch, which allows us to quickly reverse the direction of each motor, as described in the Propulsion section. (See Figure 14 for one version of our motor switch box.)

Fig 14: The unfinished motor switch box.

The tether motor power, pneumatic, and camera lines are all designed to be easy to connect and disconnect from the control box. The camera power supplies and motor wiring are plugged into a speaker terminal blocks, while the pneumatic lines feed directly into each Festo valve. The ROV is usually detached for maintenance and travel. This allows us a great deal of freedom in working on the control box separately from the rest of the robot.

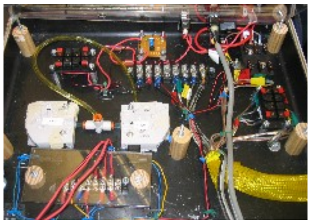
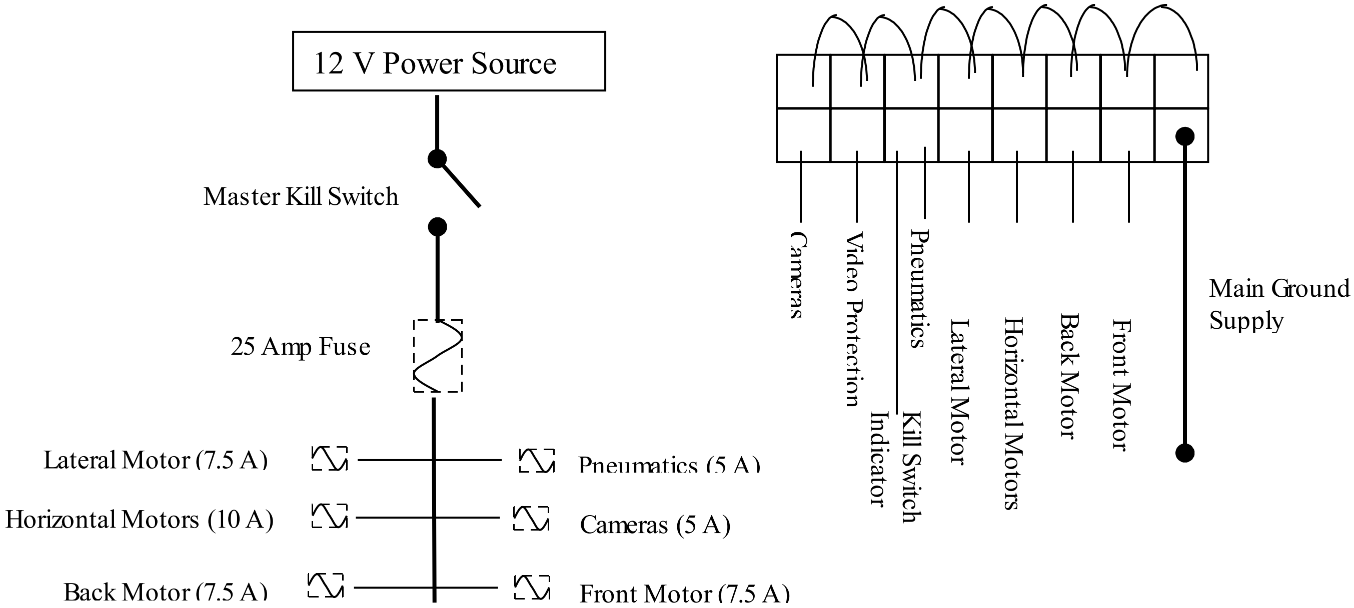


Fig. 15: The control box without the Lexan top.

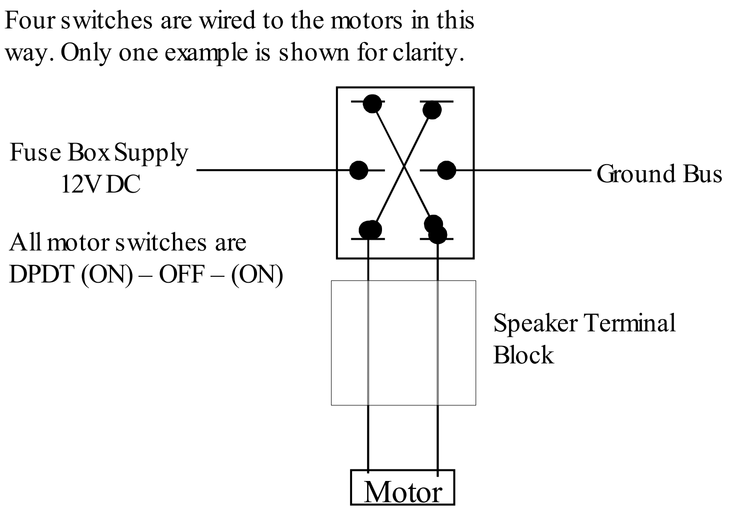
The pneumatic control switches are also located within a hand-held control unit which can be removed from the control box for ease of use. Unlike the motor switches, the pneumatic control switches are simply single-pole, single-throw, on-off switches which control whether or not the pneumatic valves have a complete circuit or not. Depending on the position, the valves allow or release air pressure for each pneumatic cylinder on the ROV, which in turn actuates a cylinder to operate one of our tools.

The camera power system is protected from reverse-polarity voltage by a dedicated relay circuit (shown on the electrical diagram). We found the circuit design online at http://www.chris.org/Modifications/reverse-polarity-protection.html. This decision was made due to the number of times we found a power source which did not follow polarity color code standards, and because we lost one of our cameras this year to reversing the wiring. From the fuse block, power goes through an on-off video control switch, through the voltage protection circuit, and into a speaker terminal block. The camera power lines plug into this block. The camera video lines feed into a quad-splitter that shows all three cameras on the screen at once. The ground lines for the quad-splitter and all the cameras plug into the speaker terminal block, which connects back to the ground bus.

Power Distribution

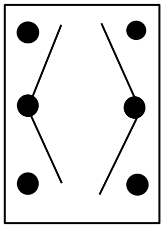


Motor Control

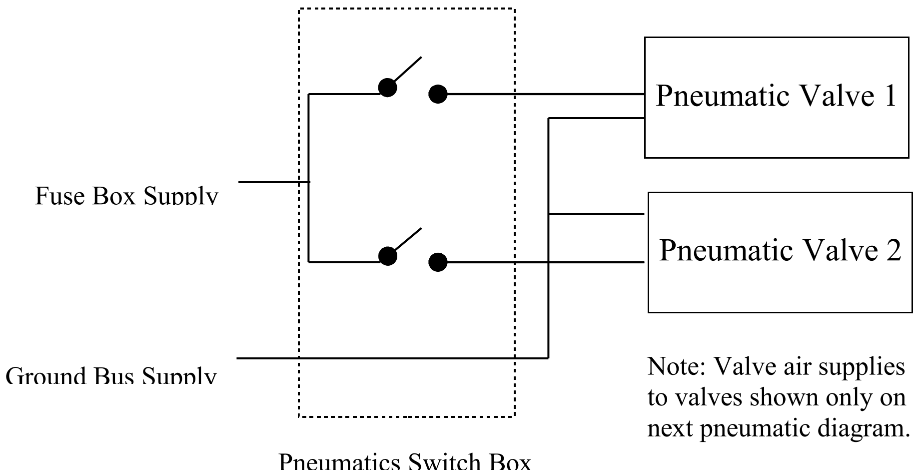

Four switches are wired to the motors in this way. Only one example is shown for clarity.

All motor switches are DPDT (ON) – OFF – (ON)

Internal Switch Contact Arrangement:

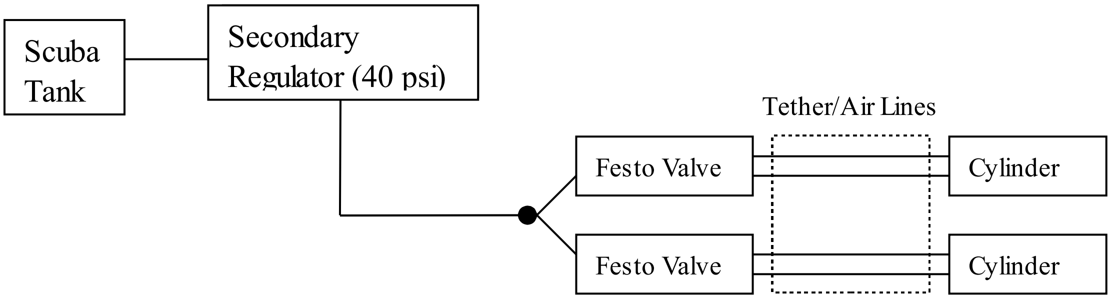


Pneumatics Control

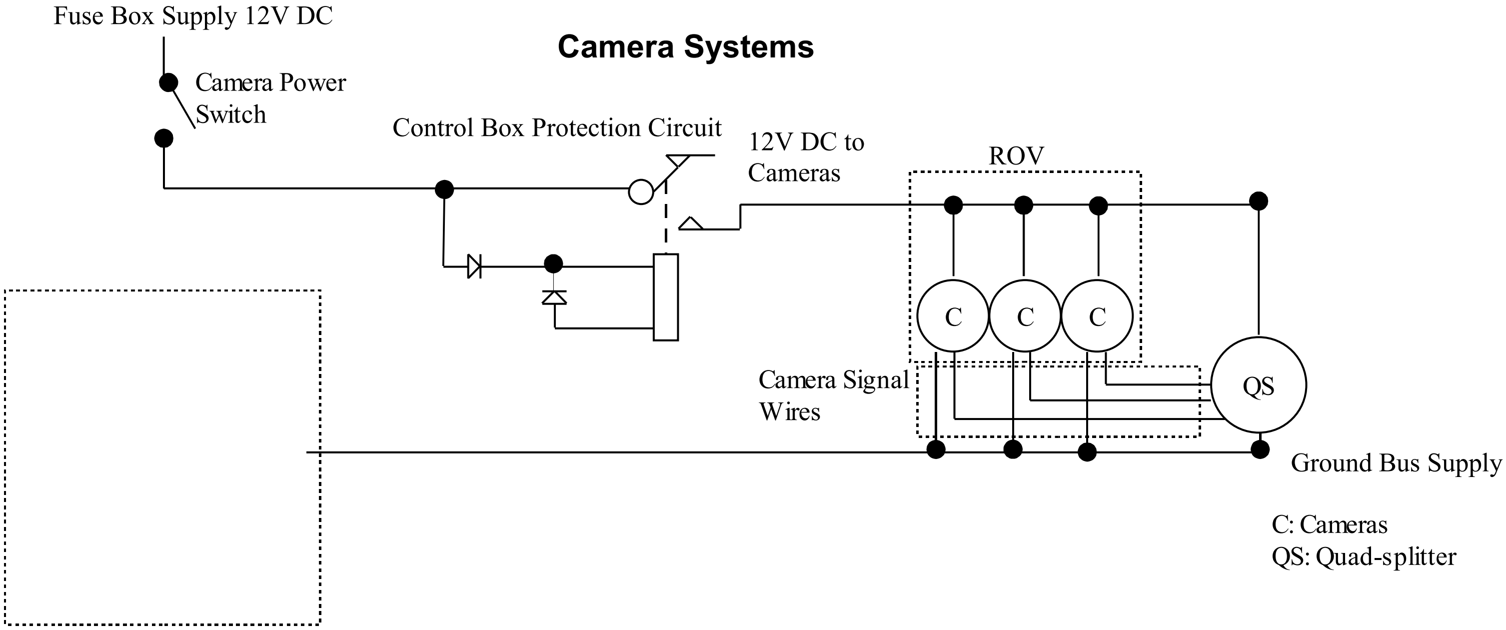


Note: Valve air supplies
to valves shown only on
next pneumatic diagram.

Pnuematic Air Supply



Camera Systems



C: Cameras
QS: Quad-splitter

Tether

Fig. 15: The inside of our tether is compact and tightly bound.

Fig. 16: The tether has extra tension control, shown here.

Our tether is composed of four pneumatic airlines to operate our pneumatic claws, three camera cables containing four 22-gauge wires protected by a durable outer sheath, and five pairs of 16-guage speaker wires for motor power. The entire tether length is 12.5 meters. Our tether is enveloped by a tough braided nylon cover. This nylon cover makes the tether very easy to handle and highly visible in the water because it is bright yellow. The nylon is woven together tightly so there is never a problem with it being snagged or ripped. It also protects the wires from physical damage due to abrasion or dragging, and from entanglement with the ROV. Flotation placed on the tether keeps it out of the way of the ROV as we perform our tasks. The tether is firmly attached to the ROV by a carabineer attached to both the tether and the ROV frame.

Buoyancy

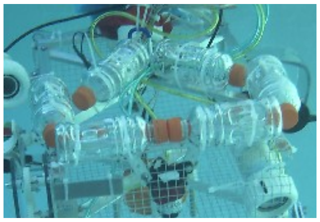


Fig. 17: The buoyancy on the ROV is easily adjustable as we added tools and weight to the frame.

In the water, our robot floats evenly just below the surface. Surprisingly, the ROV remains neutral-buoyant even at 4 meters depth due to our fixed buoyancy, which resists most compression. The buoyancy is made of Gatorade bottles mounted to the top of the frame. Gatorade bottles are easily adjustable by allowing water in them until the desired amount of ballast and buoyancy is achieved. The larger bottles are relatively strong, even under pressure, due to a strong circumferential rib design and heavier plastic than other drink bottles. Gatorade bottles are also desirable because they are transparent so they can be placed in front of cameras and we are still able to see. The ROV remains level no matter what modifications we put on the robot because our buoyancy is adjustable. Our bottles are located on the top edges of the ROV in order to supply stability.

Troubleshooting

This year, we entered the competition with more knowledge of how to maintain and manage our ROV because of our experience last year. This allowed us to foresee possible problems before they occurred. Regardless, we still encountered troubles with the ROV.

At the Monterey Regional Competition, we recognized the signs of water intrusion in a camera by the lines on the TV screen. Having had experience with this problem, we removed the housing for the camera and let it dry out, and discovered that a missing O-ring was the source of the housing failure. By recognizing the symptoms of a problem, we were able to locate and correct the mishap before it became a serious failure, and saved the endangered camera in the process.

We were able to troubleshoot with relative ease because of the ROV's design and control system. The modular and accessible nature of our control systems, including the video system, makes it very easy to use a digital multi-meter to troubleshoot and locate electrical problems. When one of our systems failed to function we would begin at the control box and check that the power source was on and plugged in. Then if the failure was related to a camera we would check that the secondary switch on the camera subsystem was functioning. Then we would search for any broken connections in the circuit and any shorting connections in the circuit. If needed, we would cut power at the master kill switch and fix the electrical issue. The master kill switch is our major troubleshooting safety precaution. It allows us to safely work on any part of the robot and control all power flow at all times.

Future Improvements

The construction of our ROV was a process of trial and error, where we learned from the errors of the previous year and worked to overcome the trials of the new one. This year, our team was comprised of students weighted down by academic, athletic, and extracurricular responsibilities that severely limited the team's work time; in hindsight, we would have had far more time to build, improve, and test our ROV if we had started earlier in the school year, instead of doing most of our work in the spring.

A technical issue that the team raised was the difficulty in using the hand-held motor switch box, which had toggle switches that were awkwardly placed, took too much force to operate, and which were so close together that changing any internal wiring was difficult and avoided if at all possible. We plan to correct this error by rebuilding the motor switch box in a larger project box, which will allow us more room to wire the switches cleanly, and extra space for placing the switches in comfortable positions, and to use switches with take less force to operate.

We continue to investigate other camera options, with a special emphasis on locating smaller, reliable cameras. Using smaller cameras in smaller housings will allow us to cut a portion of weight from the robot, which is an ongoing design goal.

These issues give us a laundry list of things to work on next year, though despite our problems we are very proud of work and what we have accomplished.

MCP Robotics Team Budget

The budget for our 2008-2009 Regional season was $1200 total, with $200 of that set aside specifically for travel costs. By watching our fund consumptions and reusing expensive parts from last year, we entered our regional competition easily under budget, with a total of $853.12 spent at that time. For the international competition we have secured additional funds for travel and other expenses.

ROV Value

Aluminum	$86
Security Cameras	$86
Quad splitter	$49.99
Camera housing parts and PVC	$149.27
Hardware	$48.42
Lexan	$44.09
Zip ties	$20.00
Electrical (Switches/Wires/Other)	$217.09
Flotation	$6.47
Sealant	$20.70
Pneumatics*	$199.52*
Motors and Props*	$100*
Tether Cover*	$100*
TOTAL	**$1,027.55**

*Denotes an item reused from 2008. In the case of pneumatics, half of that value was bought in 2008. Such dollar values are included in total ROV Value but not in Total Team Costs.

ROV Presentation Board Costs

Photos	$25.33
Poster Printing Costs (estimated)	$100
TOTAL	**$125.33**

Travel Costs (estimated)

Airfare	$3,143
ROV Shipping	$200
Gas	$400
Car rental	$600
Meals and lodging	$1,400
TOTAL	**$5,743**

Team Income

Mission College Preparatory	$3500
RRM Design Group	$300
Eagle Robotics	$150
Depth Perceptions Diving Services	$150
Team Families (Airfare only)	$3143
TOTAL	**$7243**

Total Team Costs*

TOTAL	**$6,696.12**

*Total Team Costs include all previously stated expenditures except items under ROV Values that were reused from 2008.

Team Reflection

When asked what each team member thought was the most rewarding part of this year, every individual answered that the camaraderie and responsibility of designing, building, and running an ROV was a new experience for them. Only one member returned from last year's team, and three of our members were inexperienced freshmen.

The biggest challenge for the team was overcoming their lack of experience. Together the untested team learned a number of new skills, including soldering, the proper and safe use of tools, setting up pneumatic systems, and basic camera wiring, all of which contributed greatly to our final ROV. Each of our team members learned these skills through practice and application, but they also had the opportunity to teach other team members skills which they already possessed- several of our team members already had soldering experience, and taught those who did not have this experience when their help was needed.

All of these experiences were incredibly rewarding to each individual, as most of our team members are planning to pursue a degree in mechanical or electrical engineering. Our partnership and cooperation, especially between the older and younger team members, has led the team to grow cohesively and overcome the numerous challenges we encountered.

Submarine Rescue Diving and Recompression System

The U.S. Navy uses a Submarine Rescue Diving and Recompression (SRDR) system. The SRDR contains the Assessment Underwater Work System, which consists of 2,000-foot atmospheric diving suits, launch and recovery systems, a flyaway sonar, ROVs, and associated support equipment. The Assessment Underwater Work System is the first system used when a submarine becomes disabled. In a similar fashion, our

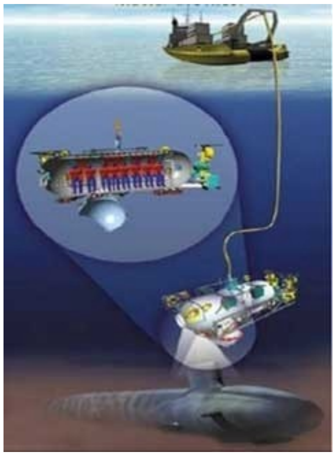


Fig. 18: A concept drawing of the SRDR system.

ROV descends toward the disabled submarine and assesses damage points around the frame using mounted cameras.

The atmospheric diving system provides rapid response capability for disabled submarine location and survey, hatch clearance, and provides emergency life support stores. Similarly, our ROV is equipped with two pneumatic claws in order to safely transport the Emergency Life Support Stores pods to the disabled submarine, engage the air valve on the ventilation system, insert the airline, and close the air valve.

Fig. 19: A cutaway image of the PRM.

The Pressurized Rescue Module System (PRMS) rescues personnel from a disabled submarine. It consists of the pressurized rescue module (PRM), transfer skirt, control van, winch, launch and recovery system, and support equipment. The PRM is a tethered ROV. Navigation, video, propulsion, and life support systems are mounted externally on its frame and hull. The ROV is designed for a depth of 2,000 feet, to dock and mate with a disabled submarine, to evacuate personnel, to provide a hyperbaric habitat, and to transfer personnel. Once submerged, the module is remotely monitored and operated from the surface. The command and control station for the PRMS consists of controls for piloting, power distribution, and monitoring life support systems. The control signals are sent to the module via an armored cable, or umbilical. The design of our ROV is similar, with a primary control box that contains pilot controls, a video system, and power distribution, and a tether that operates the motors and tools.

The PRM ROV will be remotely piloted to the disabled submarine where it will mate to the deck of the submarine over its hatch. Mating occurs via an articulated mating skirt. This subsystem allows mating to the disabled submarine at angles of up to 45 degrees. The transfer skirt is large enough so that mating, hatch opening, and personnel transfer can be achieved without removal of any disabled submarine parts. To complete the corresponding mission task, our ROV has a transfer skirt made of black ABS pipe, which allows us to mate with the simulated submarine.

References

1. Research source: http://www.globalsecurity.org/military/systems/ship/systems/srdrs.htm
2. Protection circuit source: http://www.chris.org/Modifications/reverse-polarity-protection.html

Acknowledgments

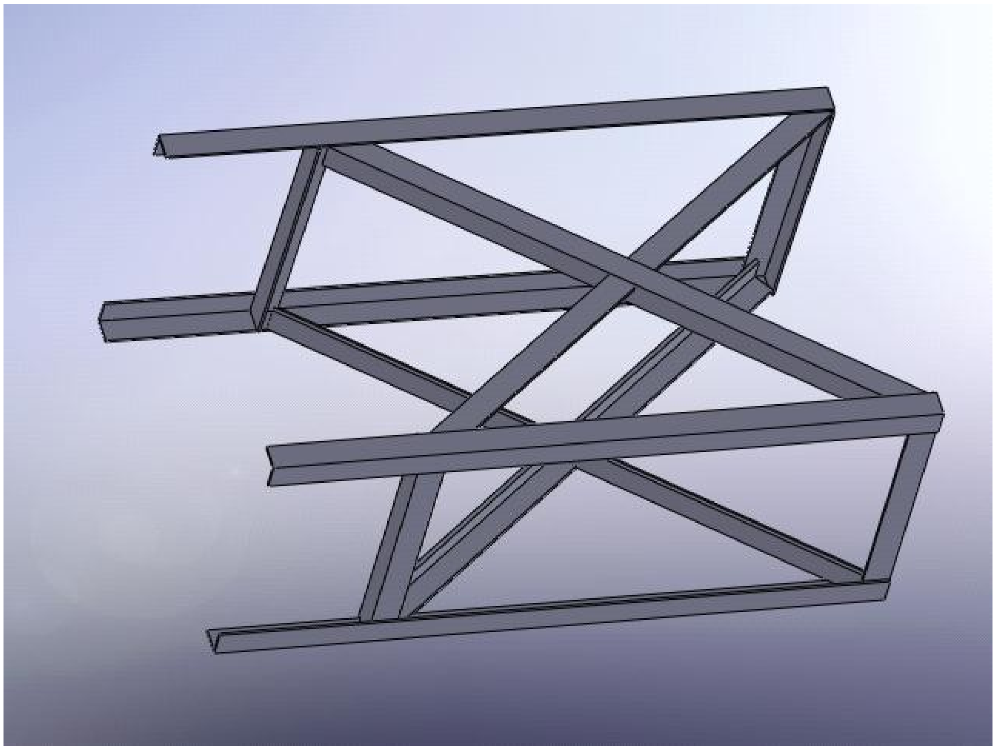
This year's Mission Prep competition team would not have been possible without the generous assistance of a number of individuals. Each and every one contributed something positive to the team. Two especially heartfelt thank-yous go out to Vickie Backman, our team mentor, and the MATE Center. Without the MATE Center, this competition and its inherently valuable experience would not exist; without our team mentor, we could never have gotten so far. Thank you.

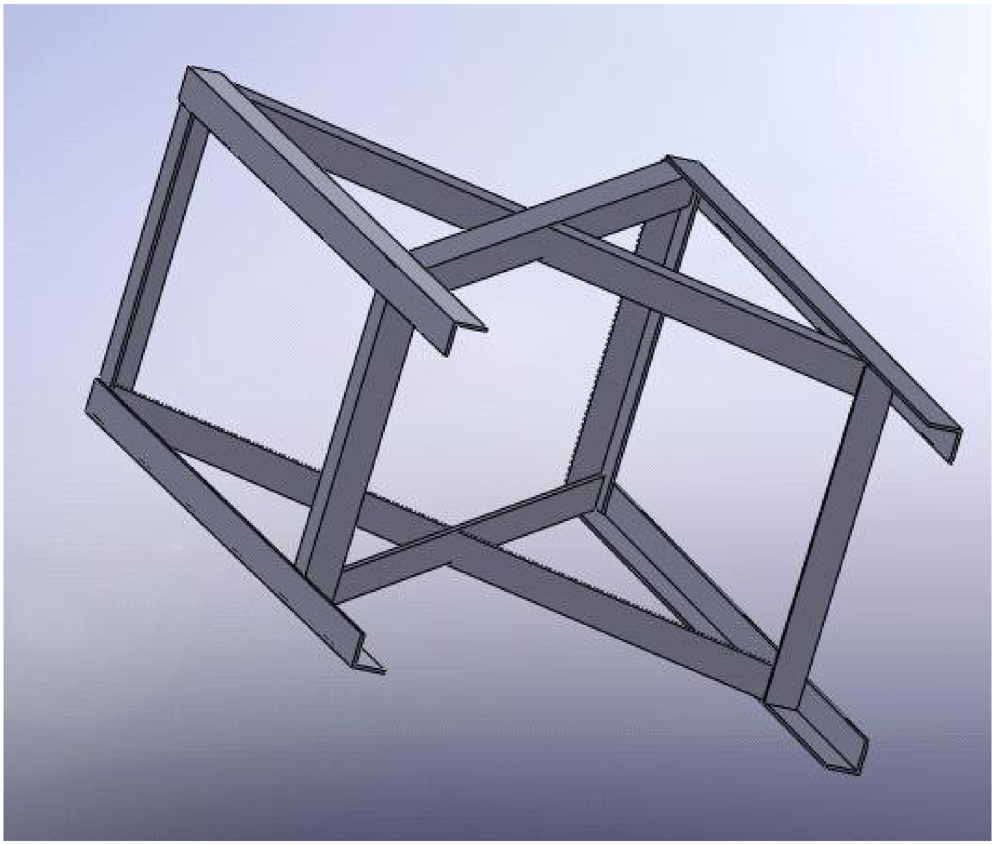
A complete list of donors, sponsors, and other important individuals is found below. Our gratitude goes out to all of them.

- Mission College Prep High School (MCP)
- The MATE Center
- Vickie Backman (MCP)
- Noah Doughty (MCP)
- Scott Frazer (Long Beach City College)
- Bill Findlay (Arroyo Grande High School)
- Depth Perception Diving Services
- Eagle Robotics
- Greyhound Revolutionary Robotics
- SolidWorks
- Absolute AutoTech

Appendices

Appendix A: SolidWorks Frame Sketches





Appendix B: Video Systems Specifications

Harbor Freight Specifications

- Input Voltage: 12V DC
- Horizontal Angle of View: 83 degrees
- Vertical Angle of View: 60 degrees
- Depth of View: 15’’
- Dimensions: 1-5/8” W x 7” L x 3-7/8” H
-

Security Camera Specifications

- Output Voltage: 9V DC
- Pixels: 300
- Horizontal Angle of View: 360 degrees
- Vertical Angle of View: 60 degrees

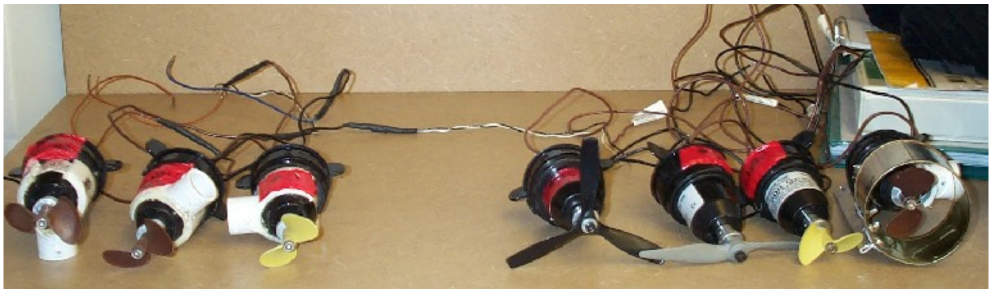
B/W Quad Splitter Specifications

- Input Voltage: 12V DC
- Output Voltage: 12V DC
- Pixels: 700
    - Picture Refresh Rate: CCIR 25 fields/sec, EIA 30 fields/sec

Appendix C: Motor and Prop Testing

Motor Number*	Forward Force [Newtons]	Reverse Force [Newtons]	Forward Amps [A]	Reverse Amps [A]
1	14.0	9.1	8.25	9
3	6.86	5.7	5	4.5
4	12.7	9.2	11	10
5	5.9	8.7	7	7
7	7.9	7.1	8	8

- Motor numbers correspond to position in this picture from left to right. Motors 2 and 6 were skipped on the table as they were duplicates of motors 1 and 3, respectively. All motors were tested under full-stop conditions, which are the conditions of highest current draw. Motors in the pool will never draw this much current unless entangled.



Appendix D: The Next Motor Mount

While not currently on the ROV, the following is a design of solid machined plastic motor mounts which will be in place for the international competition.