ROV *Castor:*
A Multi-Mission Remotely Operated Vehicle

Massachussetts Institute of Technology
Cambridge, MA 02139

M. J. Stanway, B. Brett, H. Brundage, S. Clark, L. Cooney,
J. Downey, H. Lichter, B. Myhre, T. Pennington,
T. Stefanov-Wagner, K. Stiehl, D. Walker

Dr. Franz Hover, Dr. Tom Consi

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Abstract

The ROV *Castor* was developed to be capable of completing the tasks set forward by the Marine Advanced Technology Education Center (MATE) 3rd Annual ROV Competition. It is a robust vehicle that offers many different functions and features an advanced control system with intuitive piloting. Capabilities include: depth, temperature, and linear length measurements; two grippers for object recovery; a fluid sampling system capable of capturing an undiluted sample; a hydrophone system for acoustic navigation; and a high-powered propulsion system. It will compete in the MATE competition, exploring "Mystery Reef" while completing various scientific and survey tasks using its various subsystems.

Acknowledgments

We would like to thank the following organizations and individuals for their help in this endeavor. Whether your contribution was funding, materials, lab space, skills, or good advice, our team is grateful to you.

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- The Ocean Engineering Teaching Lab
- Cape Shores Welding
- Analog Devices
- Bluefin Robotics
- Marine Advanced Technology Education Center

Contents

1 Introduction

The *Castor* remotely operated vehicle was designed to meet the requirements of the 2004 Marine Advanced Technology Education Center ROV Competition. The competition takes place on "Mystery Reef," a mock-up of a previously uncharted reef near a methane hydrate cold seep, and the site of a sunken German U-boat. Teams are given seven tasks to complete in a 30 minute time period. These tasks include temperature and depth measurements, collection of a fluid sample from a barrel, recovery of a Captain's Bell and a lost towfish, measurement of the U-boat's length, and locating and recovering an acoustic pinger. These tasks will help to the identify the wreck, find the methane seep, and analyze an unknown and potentially hazardous pollutant leaking from corroded barrels. The mission also includes the recovery of some expensive equipment.

2 Use of ROVs in National Marine Sanctuaries

ROVs are used in National Marine Sanctuaries (NMS) for a variety of missions, including scientific sampling, archaeological survey, conservation, policy issues, exploration, and education.

In the Thunder Bay National Marine Sanctuary of Lake Huron, for example, a recent expedition to explore the wreck of the *Montana* was webcast to promote better public awareness of the rich cultural record that lies under the waters of the bay. In this particular expedition, a Phantom III ROV (Figure 1) was used to film divers

Figure 1: Phantom III ROV at work in Thunder Bay NMS.

conducting a survey, and send its video feed topside to be recorded and distributed. The video was broadcast to many locations, including the American School for the Deaf in West Hartford, CT. Reaching out to educational institutions in this way is very important to future ocean research, because increasing student interest in ocean sciences is one way to insire them to enter the field. [1]

During the NOAA Ocean Explorer Sanctuary quest, an ROV from the US Navy was used to characterize the habitats both in and outside of the chin of sanctuaries the expedition visited. They visited National Marine Sanctuaries along the west coast of the US from the Channel Isalnds NMS ot the Olympic Coast NMS. During this project, ROVs investigated specific submerged cultural resources, such as shipwrecks and paleoshorelines that may have provided habitat for prehistoric humans. [2]

In the Stellwagen Bank National Marine Sanctuary, ROVs were used to positively identify the shipwreck of the *Portland*. The wreck was initially found by sidescan sonar, but the high quality video from the ROV missions showed some of the distinctive characteristics of the ship, like the rudder assembly, paddle guard, and steam release vent. These features are indicative of the class of coastal passenger steamships to which the *Portland* belonged. Since the *Portland* is the only ship of this type recorded to be lost in Massachusetts Bay, observation of these features provides positive identification of this famed wreck. [3]

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[1] Ivar G. Babb, et al. *NOAA Partnership Conducts Live Webcast from The Thunder Bay National Marine Sanctuary and Underwater Preserve.*
http://www.nurp.noaa.gov/Spotlight%20Articles/underwaterweb.html

[2] *NOAA Ocean Explorer: Sanctuary Quest.*
http://oceanexplorer.noaa.gov/explorations/02quest/background/plan/plan.html

[3] *Portland site confirmed.*
http://stellwagen.nos.noaa.gov/about/newsreleases/2002pr8-29noaa.html

3 Temperature and Depth

Two of the most useful measurements in oceanographic surveying are temperature and depth. In the Mystery Reef mission emphasizes this by requiring the depth at which the German U-Boat rests and the temperature of water coming from a cold spring (Figure 2) to be maesured.

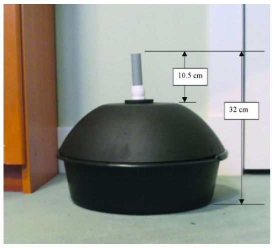


Figure 2: Methane cold seep mockup.

To measure depth, a strain gauge (Measurement Specialties, Inc. MSP 600) will be used. It measures the pressure differential across a flexible piece of material whose resistance changes with deflection. This pressure can be converted to depth:

$$D = \frac{P}{\rho g}, \tag{1}$$

where P is pressure (Pa), ρ is the density of water (kg/m^3), and g is acceleration due to gravity (9.81 m/sec). Density will differ between freshwater and saltwater. Pure water has a density of 1000 kg/m^3, and saltwater is usually about 1027 kg/m^3. This particular sensor was chosen for its high sensitivity and resolution, allowing determination of depth to within 5 cm. We did not believe that we could construct our own sensor with this accuracy.

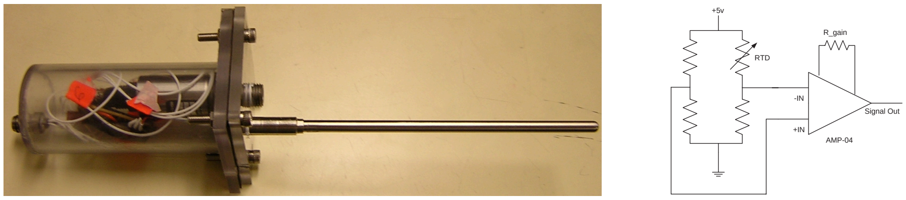


Figure 3: Temperature and depth sensor package and temperature sensor circuit.

The temperature measurements will be taken with a resistence temperature detector (OMEGA PR11 RTD). Since it did not come with circuitry in the package, the RTD was wired into a Wheatstone bridge (Figure 3) to negate part of its background resistance. The signal was then routed through an amplifier and into the vehicle's bottomside computer.

Both of these sensors have a linear output, so they will be calibrated using two known points and a fitted line.

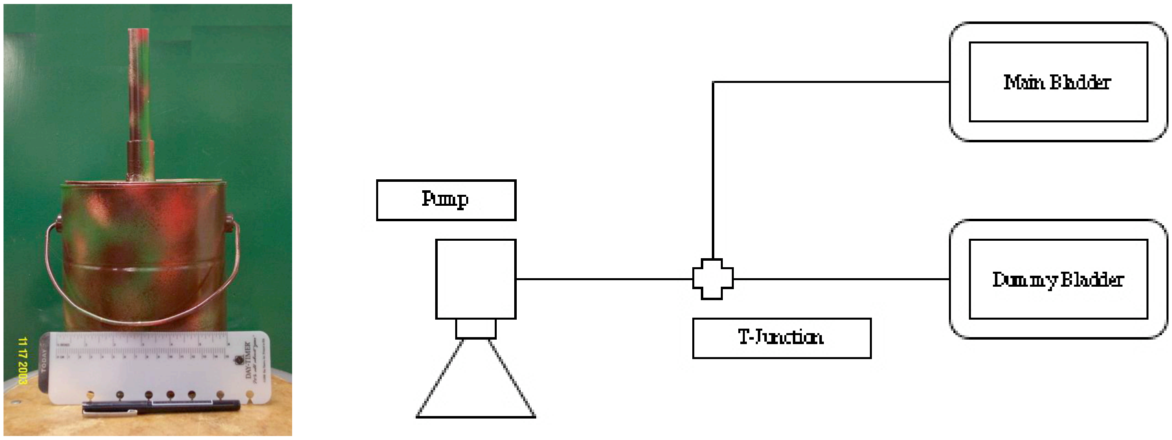


Figure 4: Corroded, leaking barrel and fluid sampling schematic.

4 Fluid Sampling

The ROV needs to collect a 500 mL sample of unidentified fluid from a barrel leaking in the mock-up. This fluid will be chemically analyzed on the surface, so it is important that it does not get diluted.

Initial brainstorming on the fluid sampling system yielded several possible solutions. Common to all the solutions was the use of a funnel for the coupling between the system and the standpipe on the sample barrel. This provides a guide to help the ROV pilot connect more easily. To provide an even better seal, the funnel will be lined with a compliant strip of butyl rubber tape in the vicinity of the standpipe diameter. Use of a vacuum container was decided against due to the difficulty in acquiring one. A syringe-type system was also pursued, but it was found to be impractical for the sample size required by the competition. The plunger of the syringe(s) would have been actuated by a lead screw, but it was determined that for syringe plungers of the appropriate size, difficulties in maintaining alignment and the large pulling force required made this solution impractical.

It was decided to use a flexible bladder fed by a submersible pump (Rule 500 Automoatic Pump 25S). It requires comparatively little energy because a flexible bladder allows for equal pressure inside and out of the system. This means the pump doesn't need to overcome very much resistance to acquire the necessary sample. Another advantage of this system is that buoyancy is not altered by sample collection. One problem that surfaced was the probability that the fluid sample would be contaminated by pool water. The pump has to be filled with liquid initially, since it is designed for liquid, and cannot be primed remotely. Somehow the water residing inside the pump housing and that in the tube must be purged or otherwise dealt with so the sample is not diluted. To deal with this, a dummy bladder was incorporated into the system. Since water tends to flow in a straight course, the pump runs through the inline section of a t-junction into the dummy bladder and off the other connector of the t-valve resides the actual fluid collection bladder. (Figure 4) The pump first fills up the dummy bladder,

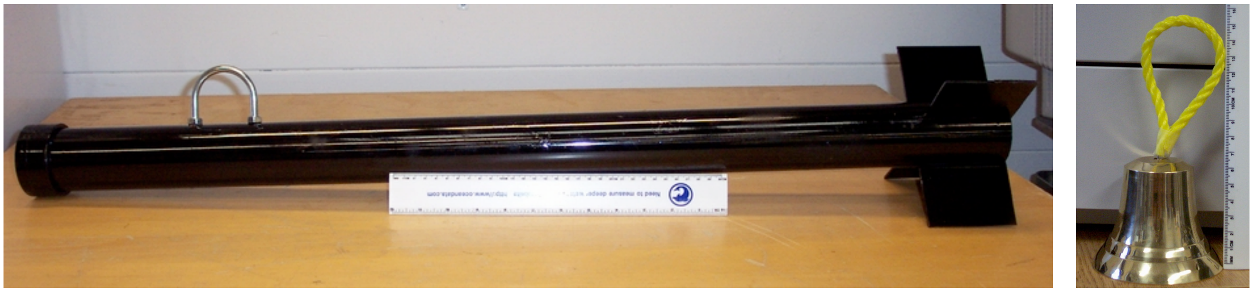


Figure 5: Recovery targets: lost towfish and captain's bell.

and then the fluid makes the turn up the t-junction to fill the main bladder with a pure sample. The bladders are both fitted with one-way input valves, so that there is no mixing after they get filled. This solution is completely passive, and works very well. In three separate tests, the dummy bladder filled completely before the sample bladder. One possible improvement is to use a reverse-wye junction in place of the t-junction.

5 Object Recovery

The ROV has three objects to recover from Mystery Reef; an expensive towfish, a captain's bell, and an acoustic pinger. To do this, the ROV is equipped with two identical grippers, one extending horizontally from the bow, and one extending vertically from the bottom. As a naming convention, the vertical gripper extends vertically from the bottom, while the horizontal gripper extends horizontally from the bow. The two grippers are designed to complete all recovery tasks, though multiple trips may be required. The towfish is a long, weighted 2 PVC pipe with a U-bolt (Figure 5).

The vertical gripper is used to grab the towfish at the center of its length, requiring less accuracy in piloting than trying to latch onto the U-bolt.

The pinger is shorter, weighted 2 PVC pipe (Figure 8). The horizontal gripper is used to grab the pinger, if the pinger is set vertically. Locating the pinger will be discussed in the hydrophone section. The captains bell is a large brass bell with a rope loop (Figure 5).

The horizontal gripper is used to grasp the loop.

The two grippers are identical, with the exception of mounting and drive shaft length (Figure 6). Each has three fingers attached to a central gearbox. The grippers use a worm drive mechanism to move the fingers in opposite directions, allowing opening and closing of the gripper. The gearbox has a central worm gear in contact with two worm wheels.

Fingers are attached to the wheel shafts, providing an opening and closing motion. The fingers are semicircular, shaped to fit around a 2 PVC pipe. One side has two fingers, while the other has one. This arrangement allows the fingers to overlap when closing. In doing so, the gripper requires little holding torque. Using a worm gear also makes the assembly non-backdriveable. Forces pulling the grasped object away from

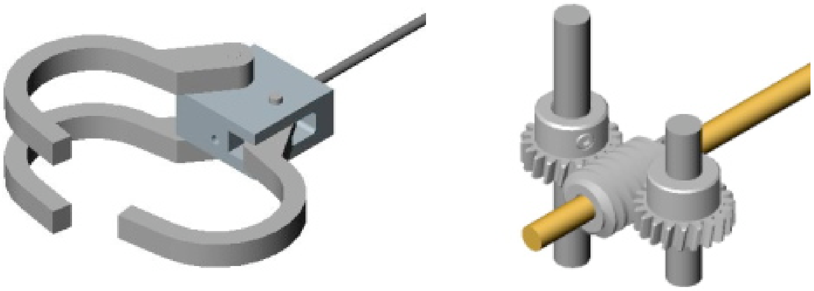


Figure 6: Gripper assembly and gearing.

the assembly are structurally opposed by the fingers, instead of by friction between the fingertips and the grasped object.

The curvature of the fingers is such that outward forces on the grasped objects force the fingers closed (Figure 7). When closed about an object, a reaction force N is generated. The force will be analyzed at an arbitrary location on the finger representing the resultant force of the pressure applied by the fingers. The force is normal to the surface of the object, and thus collinear with the radius of curvature for the finger at that point. The reaction moment generated about the center of rotation R for the finger is simply $R \times N$. This moment will be in the anticlockwise direction for the depicted geometry, thereby closing the gripper. The moment will be clockwise, or opening, if the resultant contact point is to the right of the line formed by the finger center of rotation and center of curvature. This opening of the fingers will move the resultant contact point to the left, and will reach equilibrium at the curvature-rotation line. The gripper will not be sufficiently open at this point to allow the object to fall.

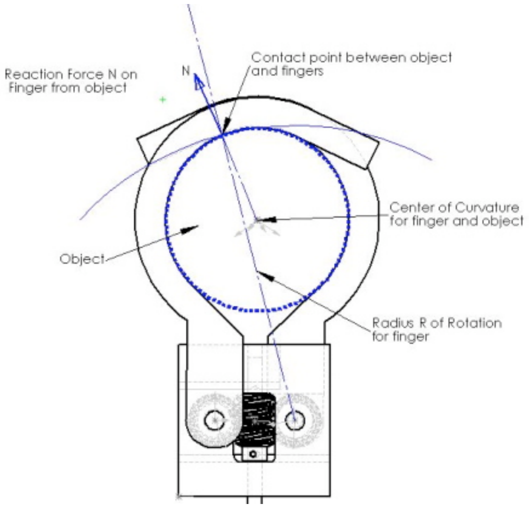


Figure 7: Force analysis of gripper.

6 Hydrophone

The use of acoustic beacons to locate sunken objects or submarine features is common in academia and industry today, since acoustic signals are well-suited to the marine environment. In the scenario of the competition, a pinger was dropped when the towfish was lost, to make the towfish easier to locate when the recovery team returned to the site. This pinger must also be located and recovered.

Figure 8: Acoustic pinger.

Its output is specified to be in the range of human hearing (20-20,000 Hz) and transmitting a signal one to two times per second. There will also be four "dummy" pingers in the competition area that do not output any acoustic signal. The ROV must be able to discern the real pinger from the dummy pingers.

Initially, a hydrophone to listen for the pinger was constructed by enclosing Radio Shack microphone elements in film canisters filled with vegetable oil. These proved to be too weak, and the canisters distorted the sound. As an alternative, microphones that were manufactured waterproof were used (Knowles Acoustics MR-8406). These microphones were designed to work in up to 15 meters of water.

To determine the direction to the pinger, three microphones were going to be used. By measuring the time difference of the signals between the microphones, the heading of the pinger could be triangulated.

Our first attempt at rectifying the signal was quite a complicated one using several diodes, capacitors, and resistors. This solution actually worked with a sinusoidal signal from the function generator on the prototyping board; however, it would not work with the output from the microphone. Another solution is using the integrated circuit LM3915. This IC detects the intensity of the sound output, so rather than finding heading based on the relative times that the signal is received, the heading can be determined based on how loud the signal is in each microphone. This is still a viable solution, and is worth looking into in the future. Yet another solution is to use a comparator, which can be configured to takes an oscillating input signal and translate it into negative or positive saturation, in our case, 0 or 5 volts. This basically makes a square-wave signal from a sinusoidal input, something that can be used more easily by computers. The comparator was made using an LM311 IC, a high-gain differential amplifier. It turned out that the comparator circuit needed to be calibrated for each microphone.

In the end, time was running out and the system was not working reliably. Our contingency plan is to put audio signals from two hydrophones directly up the tether, and compare intensities by human hearing.

7 Length Measurement

For the task of measuring the U-boat's length, we considered a few options. Running a tape measure seemed like it would work, but wasn't something that would be used normally by an ROV. Using a laser-based system would have been difficult to implement, though perhaps the most robust and most accurate. We opted for a visual measurement. By taking an angle between two reference points, moving a known distance closer (using a change in depth from above) and taking a new angle, the length between the reference points can be calculated:

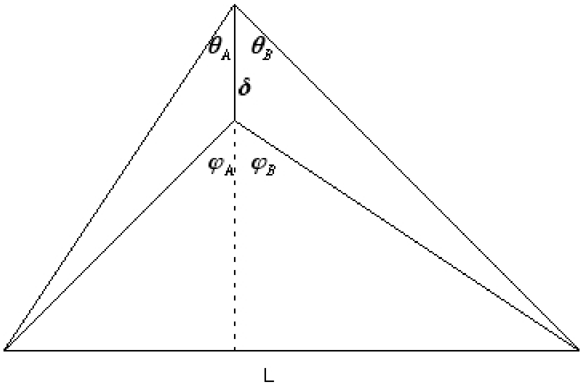


Figure 9: Geometry of length calculation.

$$L = \delta(\frac{\tan\theta_A \tan\varphi_A}{\tan\theta_A - \tan\varphi_A} + \frac{\tan\theta_B \tan\varphi_B}{\tan\theta_B - \tan\varphi_B}), \tag{2}$$

where L is the length to be measured and the angles are as shown in figure 9.

We are interested to see how well this method works, though we don't know if we will be able to meet the accuracy requirements of the competition.

8 Propulsion

For propulsion, we will be using three small trolling motors (Figure 10) and three smaller bilge pump motors. The trolling motors have 44.5 Newtons (10 pounds) of thrust, and are used for forward propulsion and vertical movement. The bilge pump motors have been retrofitted with standard propellors instead of their original impellers and have been placed orthogonal to the other motors to provide an extra two axes of control. Two of the bilge pump motors are mounted in the horizontal plane to produce left/right translation. One bilge pump motor is mounted vertically, to control pitch.

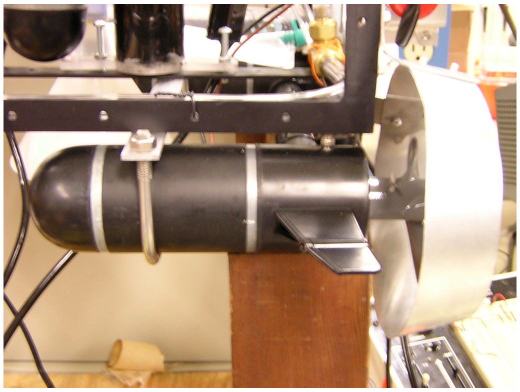


Figure 10: Trolling motor.

The trolling motors were originally outfitted with propellors that produced thrust in only one direction. We tried several other propellors in order to find one that could also produce thrust in reverse, however none of the propellors were well suited for the motor characteristics. They either produced much less thrust or consumed more power (one test propellor looked promising until its power drain was measured to be twice that of the standard propeller.) In the end, we decided to use the factory provided propellors, but retrofit them with a shroud. During testing, we noticed that the propellors would throw a lot of water outwards when running in reverse. Thus the idea came up that if we could somehow redirect that water that was being thrown outwards, thrust could be generated. To that end, a tapered cowling was built and installed. It functioned as expected, producing around 9 Newtons (2 lbs) of reverse thrust when the propeller was running backwards, and creating minimal impact on the forward thrust. Considering that there was virtually no reverse thrust before, this is a definite improvement and it will allow us to back out of enclosed spaces without having to turn around first.

9 Controls

The Advanced Marine Integrated Guidance and Operation System(AMIGOS) is a system that accepts ROV operator commands, provides rapid communication to and from the ROV for relaying instructions and returning useful data, and controls all aspects of the vehicles operation. The operators should be unconcerned with how data is transmitted throughout the system or output device settings are calculated, and therefore able to focus exclusively on driving the vehicle. Two team members, designated as the mission commander and payload specialist, can control the entire system by themselves, using two straightforward input devices. The systems must also be highly modular, easily expanded to accommodate additional propulsion units and input/output peripherals, such as data acquisition modules, mechanical arms, and fluid collection units. An array of onboard video cameras, selected by the electronic control circuitry, is another goal of this system.

The ROV is driven via Playstation controllers, connected to a microcontroller on

Figure 11: Playstation controller functions.

the surface, and the controllers also update the video displays, move the cameras, set the vehicle depth, initiate various system functions such as fluid sampling, and operate the mechanical arm.

User input is processed and constructed into data packets by the Topside Computer, which then transmits these to the Onboard Computer through a data line in the tether. The Onboard Computer receives and decodes the packets, sending commands to the numerous connected peripherals. These include expansion boards that interface with the motors and servos, as well as a four-way video switcher. Data from all subsystems is recorded and made into packets by the Onboard Computer, which are subsequently transmitted serially to the Topside Computer on request. The Topside Computer feeds data and state information to a laptop computer screen, and two other laptop screens display the selected video signals.

9.1 Playstation Controller Interface

Playstation Controllers (Figure 11) are used for input by the Mission Commander and Payload Specialist. These were selected for their ergonomic shape, familiar button arrangement, and straightforward operation. Reverse engineering of this product was accomplished by interfacing it with a PC, which simulated the output Playstation Game System and allowed us to determine exactly how the controller responded and formatted its data.

Although the controllers plug into the ports on our Playstation shell used to house the Topside electronics, all of the signal processing is accomplished by the Playstation Adapter Board. We custom-designed and assembled this board (Figure 12) for use in the AMIGOS system.

A crucially important aspect of this project was deciding how controller inputs would map to functions of the ROV, a classic example of human factors engineering. Our goal was to limit the responsibilities of the Mission Commander and Payload

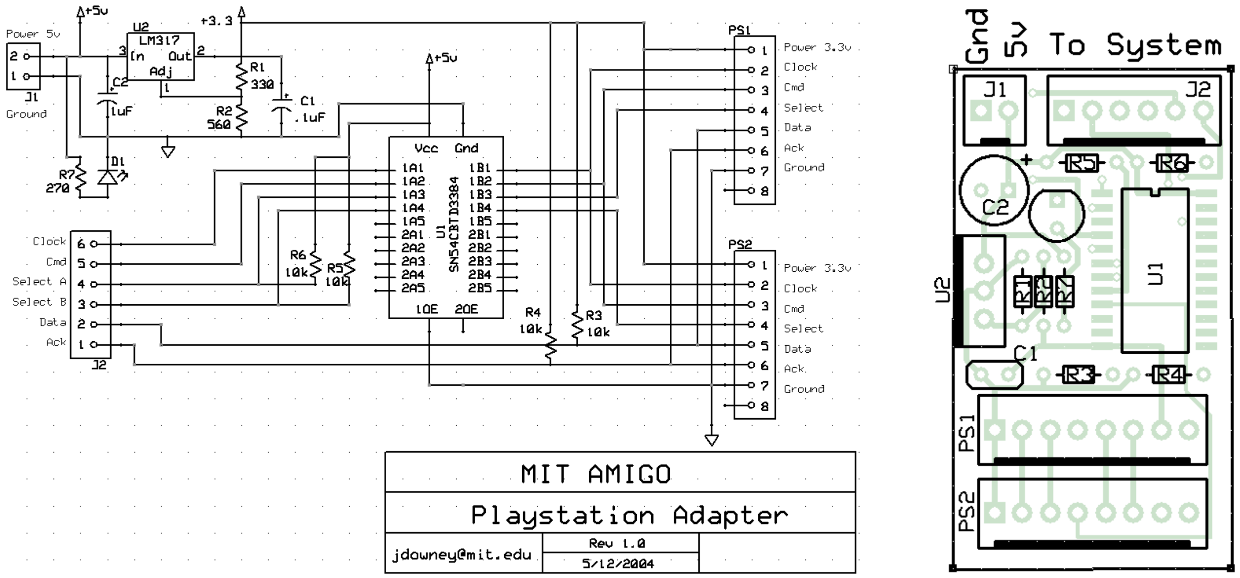


Figure 12: Controller adapter schematic and PCB layout.

Specialist, so each operator could focus on his assigned tasks. The resulting design differentiates between the two controller ports to accomplish this.

Controller 0, which corresponds to the Mission Commander, maneuvers the ROV and can control the video feeds. In default operation mode, the analog joysticks are used for vehicle motion. The right joystick controls forward motion (y-direction) and rotation (x-direction), while the left sides x-direction moves the ROV laterally. The L1 and R1 buttons scroll through the camera displayed on the right and left screen, respectively. When one of the Move Screen Enable buttons are pressed (L2 or R2), the right joystick instead tilts and pans the camera currently active on the display screen. Clicking the left controller places it in control of the vertical thruster power, and a second click return the unit to default operation. Finally, up and down on the keypad increment and decrement the depth of the ROV in inches, and holding down the circle button scales these depth changes by a factor of twelve.

Controller 1, which corresponds to the Payload Specialist, operates the vehicle subsystems and can also control the video feeds. When the up button is pressed, the triangle and x buttons open and close mechanical arm A. When the down button is pressed, the triangle and x buttons open and close mechanical arm B. Holding the left button while pressing the triangle or x starts or stops the fluid sample pump. The right button is currently unassigned, but the programming could be easily modified to support a fourth system command. The video selection and switching is exactly the same as controller 0.

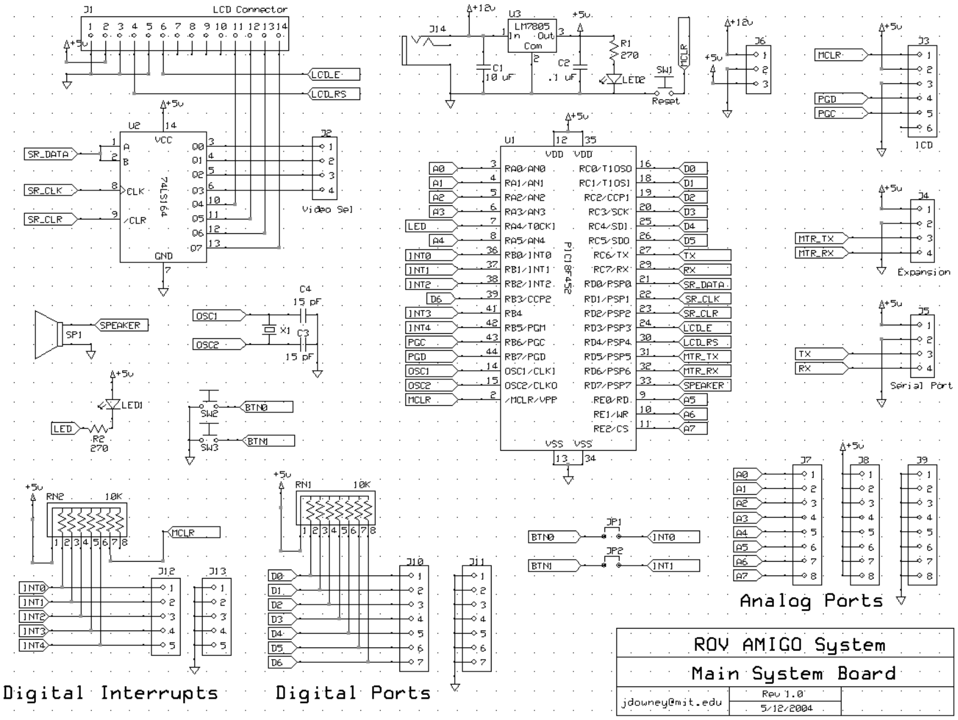


Figure 13: AMIGO main board schematic.

9.2 Topside Computer

An 18F48 PIC microcontroller is the heart of our Topside Computer, which serves as the master board, regulating and directing the transmission of serial data between surface and the ROV. Figure 13 is a schematic of our circuit on the printed circuit board. The PIC is surrounded by a shift register, clock, input buttons, and numerous user interface ports.

Once the user has turned on the board with the Playstation case reset button, the microcontroller initializes variables and begins the data transmission while loop. The procedure is composed of three major sections: the controller update, motion update, and data request.

Most of the decisions are made with each call of the function update_controller, which receives the controller id (0 or 1) as its single argument. After determining that the specified controller is properly attached, this routine looks for any button state changes since the last time it ran update_controller, which would indicate a press or release. On each button press, the microcontroller plays a tone and checks through a series of switch statements to see if there is any action associated with the press of that button. With the present design, only pressing one of the camera move enable buttons (L2 or R2) has any meaningful effect. The button release routine incorporates many more function calls, including disabling move camera, switching the selected video feed, changing the vehicle depth, or executing a system command.

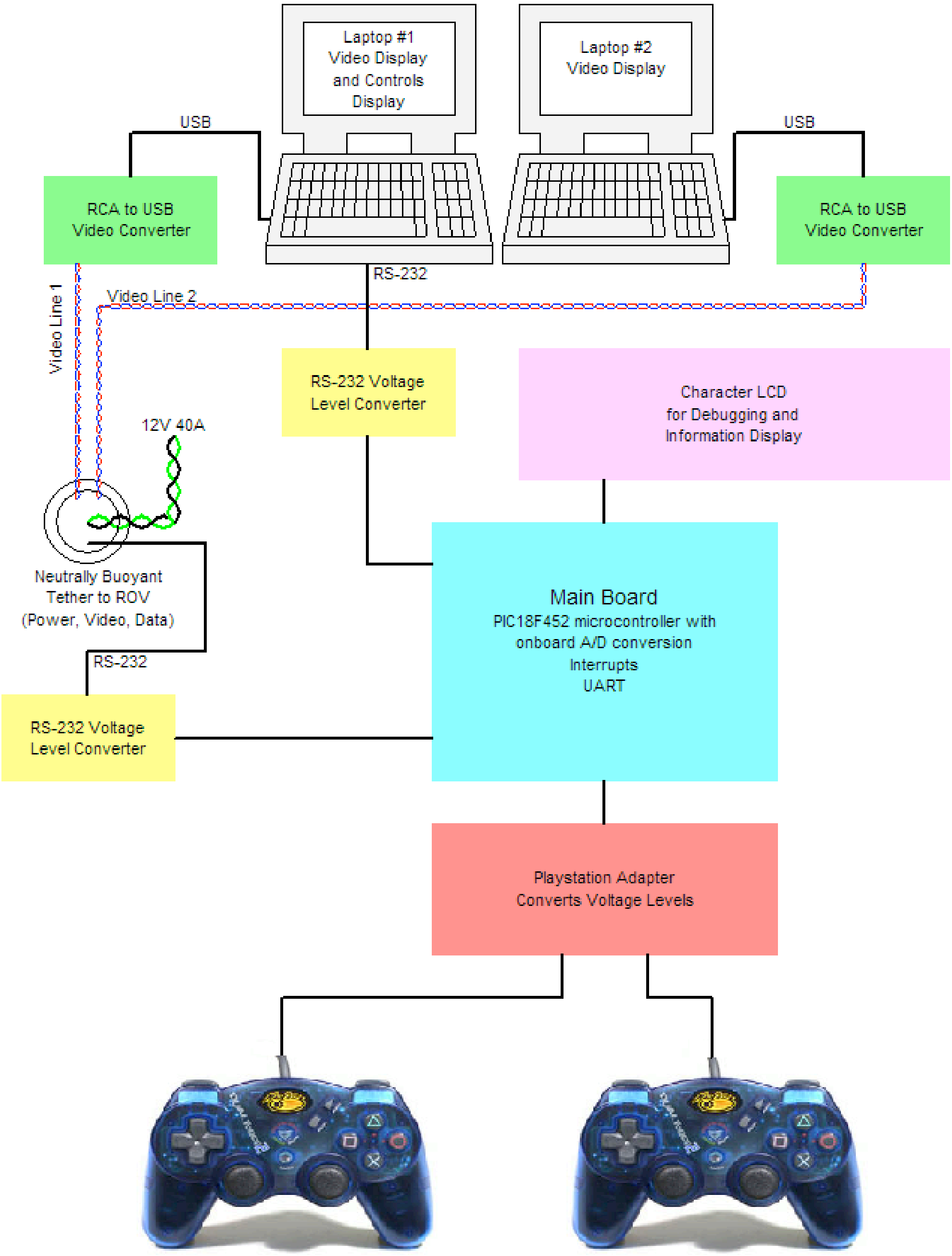


Figure 14: AMIGO topside system.

If the driver is moving a video camera, his joystick motions have no effect, but otherwise the motor speeds are adjusted based upon these settings. The function that accomplishes this is called tether_update_motion, and it creates a packet of the desired forward, rotational, horizontal, and depth related values. In the case, the only computation by the Topside Computer is a normalize function, which centers the values at zero instead of 127 and creates a dead zone around this center value to prevent slight joystick inconstancies from turning on the motors.

Every ten cycles through the while loop, the Topside board requests any data that is available from the Onboard Computer. This function, as with all the others that relay data along the tether, expects acknowledgement of the sent packet, and it will repeat the transmission up to a specified number of times until that happens. If the transmission never succeeds, the blue LED indicator light on the Playstation case is turned off.

In addition, every tenth of a second a timer interrupt checks if either operator has enabled camera movement, responding by calculating and transmitting the updated camera servo position to the appropriate camera.

9.3 Onboard Computer

Below the surface, the AMIGOS features a marvelous example of modular design and a high degree of expandability. Expansion cards, such as the Motor Controllers and Servo Controller (Figure 16), are daisy-chained along a serial transmission line. Commands are addressed to a specific device on the chain, and the system could theoretically handle 255 connected expansion boards with the current architecture.

The Onboard Computer (Figure 15) receives and sends packets at the request of the Topside Computer, while rapidly carrying out these instructions. Update_Motion, Move_Camera, Update_Video, System_Command, and Request_Data are the current possibilities.

When Update_Motion relays information , the Onboard Computer does the major computational work. It depends on an array of user specified constants to describe how the given motor functions, including scale factors to handle differences in overall thrust, a positive cutoff value for each motor, and a negative cutoff value for each motor. Output levels, as a positive or negative percentage, are determined by combining weighted inputs from the three controller directions:

- Motor Left = (forward_power + rotational_power)*(1/(forward_factor + rotation_factor))
- Motor Right = (forward_power - rotational_power)*(1/(forward_factor + rotation_factor))
- Motor Front = (rotational_power + horizontal_power)*(-1/(rotation_factor + horizontal_factor))
- Motor Back = (rotational_power - horizontal_power)*(1/(rotation_factor + horizontal_factor))

These are mapped to pulse width modulation values by a piecewise function, defined by the cutoffs and breakpoints custom set for each motor.

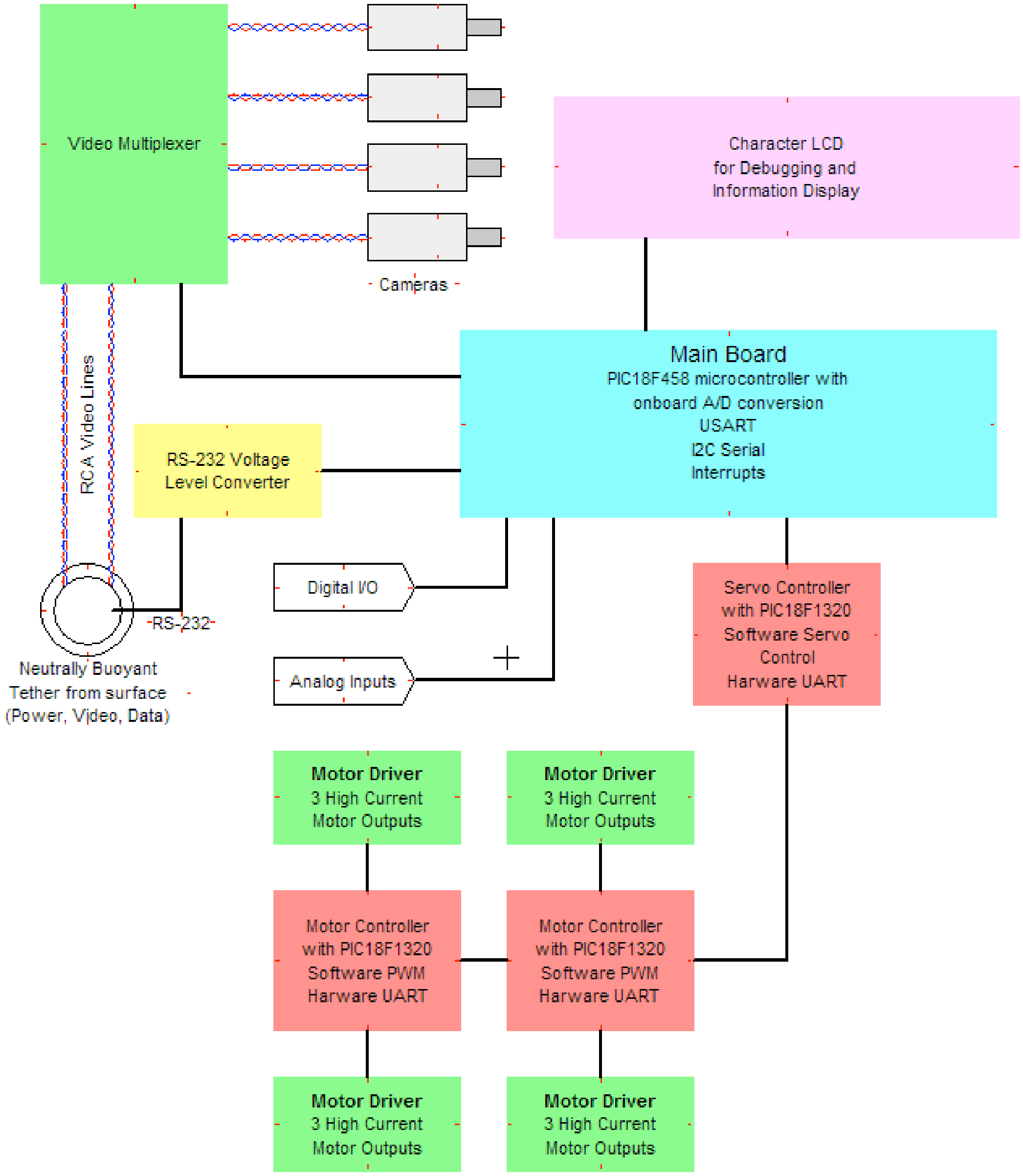


Figure 15: AMIGO bottomside system.

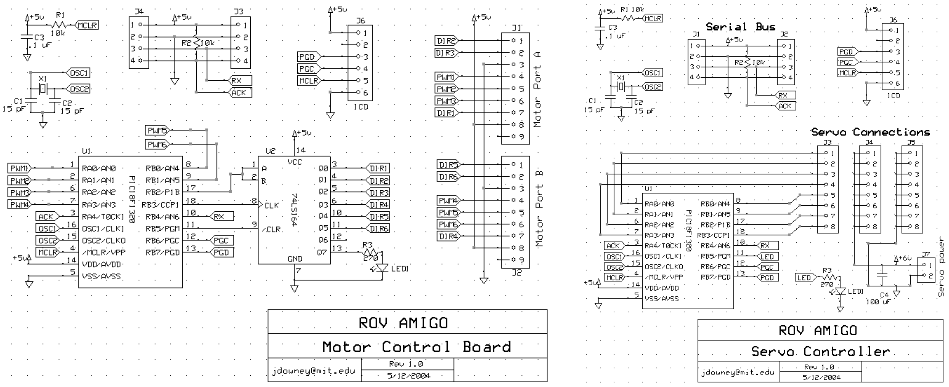


Figure 16: AMIGO motor controller and servo controller schematics.

The arrival of Move_Camera updates a corresponding servo position, between 0 and 180 degrees. To maintain its position, a servo must be continuously refreshed with pulse width modulation signal of the appropriate duration. These servos refresh at approximately 60 Hz, so the new position should be applied to the device within .0017 seconds of data decoding.

The Video Switcher board receives control signals in response to Update_Video commands. The switcher receives four video signals, and our controls signals independently select which will be placed on each of the tethers two wire pairs dedicated to video transmission.

A given System_Command enables or disables certain output devices connected to the computer, and a packet containing ROV state and sensor value information is relayed in response to Request_Data.

9.4 Motor Control Board

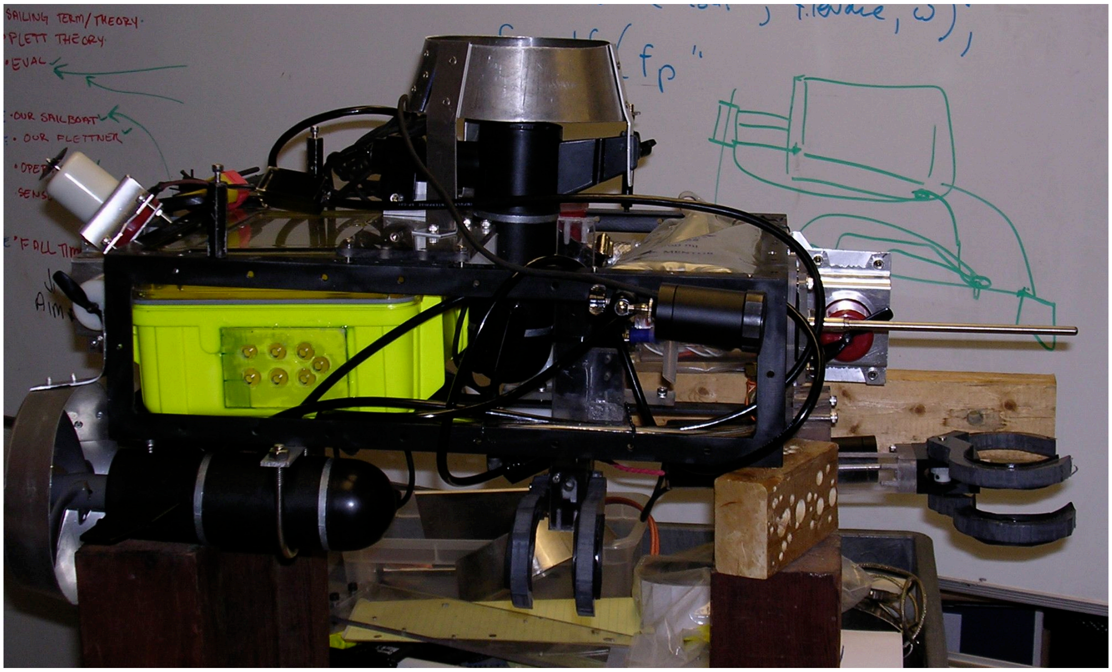
Our AMIGOS motor controller boards feature the 18F1320 PIC microcontroller, which receives serial data, acknowledges successful packets, and provides direction and pulse width modulation values for up to six motors, attached three per side to Motor Port A and Motor Port B. The six motor directions are stored in a 74LS164 shift register as single high or low bits. This device accepts a serial input from the PIC to produce the desired six outputs, and the shift register also controls the LED state.

9.5 Servo Control Board

The Servo Control Boards also use an 18F1320 PIC microcontroller to handle the serial communication and generate output signals to the attached servo motors. This component is complicated because the servos must receive pulse width modulation refresh from the PIC at regular intervals to maintain the desired values. At the same the, the PIC must be receiving and acknowledging packets of information. The PIC utilizes multiple timers to signal the refresh cycle and send highly accurate pulse width modulation values. To accomplish these necessary activities in the narrow refresh time window, servos 0 to 3 are refreshed simultaneously, followed by the reception of data waiting in the serial bus buffer. This interval is short enough to prevent the buffer from overflowing. Then servos 4 to 6 are refreshed in the same manner. Processing packets and updating the servo values occurs at this time.

10 Integration

To pull all the subsystems of the ROV together, a welded aluminum box frame from last year's competition was used. The frame facilitated our modular design with many 10-32 tapped holes along all sides. Electronic connections into the watertight bottomside control boxes were made with Impulse submarine connectors. The link to the surface consisted of large gauge speaker wire to provide power, and a neutrally buoyant tether containing 3 twisted pairs and four other conductors, for a total of 10. All efforts were made to keep the system as modular as possible to ease the replacement and/or maintenance of separate subsystems, as well as to allow repositioning as needed.



The Remotely Operated Vehicle *Castor*

11 Final Budget

Category	Item	Quantity	Cost	Total	
Electronics	Playstation Controller	2	30.00	60.00	
	PCB Fabrication	4	60.00	240.00	
	PIC Processors	6	11.00		
	C18/MPLAB		FREE		
	Misc. Components	1	100.00	100.00	
	Underwater Connectors	11	80.00	880.00	(Salvaged)
Travel	Team Member Ticket	10	400.00	4,000.00	
	Robot Shipping	1	150.00	150.00	
	System Packing (case)	1	20.00	20.00	
Sensors	Depth Sensor (gauge)	1	110.00	110.00	
	RTD Element	1	20.00	20.00	(Salvaged)
	Depth sounder	1	150.00	150.00	
	Hydrophone	3	35.00	105.00	
Retrieval	Gripper Motor, Materials	2	40.00	80.00	(Salvaged)
	Liquid Sampling Pump	1	20.00	20.00	
	Liquid Sampling Tubing, bags	1	30.00	30.00	
Buoyancy	Structural Foam	1	200.00	200.00	(Salvaged)
Propulsion	Trolling Motors	4	70.00	280.00	
	Bilge Pumps	4	20.00	80.00	
Integration	Frame	1	200.00	200.00	(Salvaged)
	Various Connectors	1	100.00	100.00	
	Tether	1	80.00	80.00	
	Materials for bracketing	1	100.00	100.00	(Salvaged)
Video	Cameras	4	110.00	440.00	(Salvaged)
	Multiplexer	4	7.00	28.00	
	Misc. Components	1	75.00	75.00	
Documentation	Poster	1	50.00	50.00	
	Booklets	20	2.00	40.00	
	T-shirts	15	15.00	225.00	

TOTAL	7,863.00
Total Subtracting Salvage	5,963.00