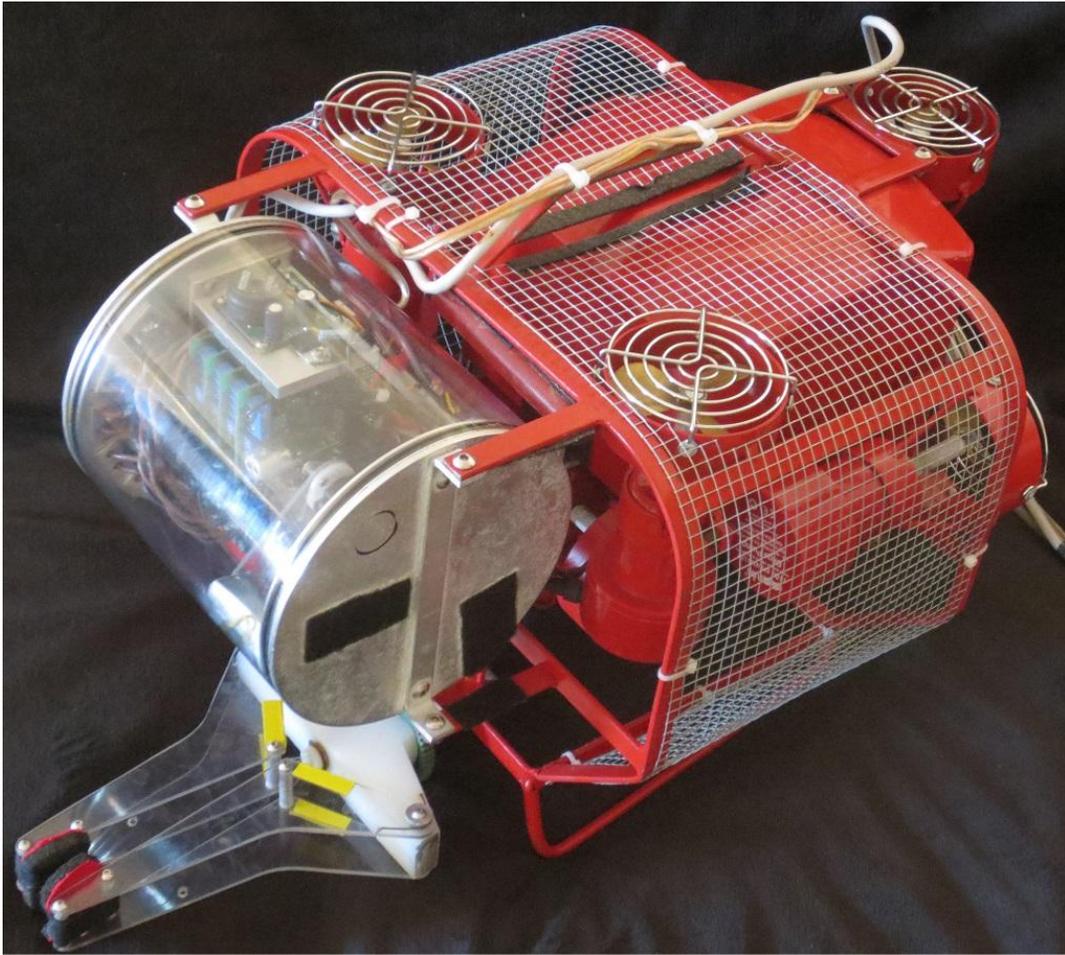


Typewriter Repairmen  
2013 National Underwater Robotics Challenge  
Technical Report

Team Members: Jim Forbes, Steven Forbes, Janet Forbes



ROV: Babs

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## **Abstract**

The Typewriter Repairmen robotics team designed and built an underwater Remotely Operated Vehicle for use in the 2013 National Underwater Robotics Challenge. The team analyzed the mission requirements, and designed a small, robust, robot with all the necessary degrees of movement, a versatile vision system, a capable manipulator, and limited instrumentation. Cost, construction methods, and materials availability factors drove many of the design features. Reliability and maintainability were incorporated into the design. Team members used commercial software tools to model the mechanical and electronics designs, and learned new building techniques. The ROV operates on solar power, generated by a photovoltaic panel, and stored in sealed lead acid batteries. The ROV was tested extensively before the competition.

## **Team History**

The Typewriter Repairmen robot team formed in 2009. Our goal is to have fun together as a family, playing with robots, and hopefully inspire others to get into technology. The team has had the following Forbes members over the years: Jim, Janet, David, Steven, Gary, Kevin, and Linus. We have also included Katie Roch, who is Kevin's girlfriend. This year, we are down a few members. David, Gary, and Linus have split off as part of the Bit Buckets team. Kevin started the University of Arizona CATfish AUV team. That leaves Jim, Steven, and Janet as the remaining team members.

## **ROV History**

The Typewriter Repairmen built the ROV NotBob our first year. The following year we built Babs. Then we modified Babs and NotBob for the 2011 NURC mission. Last year we built an Autonomous Underwater Vehicle, Biff. This year we decided to again modify Babs and enter NURC. This year's modifications mainly deal with how to make Babs work in the Nebula.

## **Determining Design Requirements**

We used a systems engineering approach to decide how to build the ROV. The first step was to carefully read the competition rules to determine the requirements for each task. They can be categorized by the type of robot action required to perform the task. What became immediately obvious is how many points could be achieved with a simple ROV with a high degree of mobility and visibility. Because these features are also required to complete the other tasks, it became our primary goal to have a very maneuverable ROV with sufficient lighting and cameras to give the pilot a good sense of the vehicle's surroundings.

Because a large portion of the mission points can only be obtained with a retrieval device, the next most important design priority for the ROV is a gripping device capable of completing most of the manual tasks required of the robot.

## **Final Design**

After much consideration, we decided to make an ROV with a basic design concept that resembles some commercial ones. The main design requirements are high maneuverability and good vision, so the ROV must have powerful forward and vertical thrusters, but it also needs to

be able to steer and move sideways. This means that the forward thrusters should be mounted on the sides and be controlled independently, to provide steering torque. Side movement without turning is called strafing, and requires a lower power thruster mounted in the center of the ROV, pointed to the side. This drive setup gives full control of the ROV.

Vision is a vital part of the ROV, and having great vision requires both a camera that can look in all directions, and plenty of light. Since the ROV can drive in all directions, but stays right side up and mostly level at all times, a forward looking camera cannot see what is below. One solution is to let the camera tilt downward, but this requires a dome of some type. Since the ROV can easily turn to see what is around the sides, the camera and dome don't need to allow panning action or vision, only tilting. An easy way to make a "dome" that only works for tilting is to use a clear tube, placed horizontally.

We settled on a total of six thrusters: three vertical thrusters, two forward thrusters, and one side thruster. The rear flotation chamber allows a rear vertical thruster to sit behind it, giving pitch control. The entire configuration gives Babs five degrees of freedom: translation in all three dimensions, turning on a horizontal plane (yaw), and pitch.

Since we needed six thrusters, we decided to make them as identical integrated assemblies. By making the motor clamp and the propeller shroud of steel, we could weld them together and have a single steel part that could be welded to the frame. Alignment between motor and shroud is critical, so we made a jig to hold the pieces for welding (Figure 1).



Figure 1

We made our own brass propellers from nuts and sheet brass. Making the propellers accurately requires a jig, so we made one of steel (Figure 2). This made it easy to silver solder the blades to the center nut at the proper angle. After attaching the blades, we used pliers to form them into their final shape.



**Figure 2**

The parts of the ROV need to be held together in a way that puts weight down low for stability, provides as little drag as possible to reduce thrust requirements, is strong, and can be easily fabricated and modified. Structural steel satisfies all these requirements.

The electronic control system is housed in a clear cylindrical compartment at the front of the robot. It also holds a pivoting structure that holds the tilting camera/light assembly. The control system compartment receives power and signal from the surface via a tether. 48v power is used to minimize the cable size, and an Ethernet cable is used to send control signals to the ROV and return vision and sensor signals to the surface. Six thrusters are used: two to provide forward/reverse and turning motions in the horizontal plane, three to allow for vertical motion, and one to allow for strafing movements (sideways motion in the horizontal plane). The frame is made of steel strap. A syntactic foam buoyancy float fits between the thrusters at the upper rear of the ROV.

## **SCULL**

We used a transparent, horizontal tube to house the electronics, lights, and camera. This design configuration provides the ability to see in all directions, using only one axis of camera motion. The entire ROV is “panned” to see to the side and the camera and lights are tilted to see up or down. Besides making the ROV very capable, this method of building the housing is relatively easy to seal. The tube has a metal plug at each end, sealed with an O-ring. The Sealed Compartment for Underwater Lights and ‘Lectronics (SCULL) which houses the onboard

control system, camera, and lights is made of polycarbonate tube and aluminum plate. The design work was done by sketching it on paper, then modeling it with SolidWorks CAD software. The 3D model was very helpful for laying out the locations of the various parts, and to make sure they would all fit in a tight package.

The polycarbonate tube is 3mm wall thickness, 150mm diameter and 250mm long. Two 12mm thick, turned aluminum end plugs with O-rings and flanges keep water out and provide mounting for electronics and wires. The end plugs started as a single solid rectangular bar of aluminum, from which two squares were cut with a band saw. Each of these was then drilled and tapped so it could be bolted to the lathe faceplate. The square plates were turned round to fit into the ends of the tube, with a step to keep them from going in too far. Then an O ring groove was turned, and the holes for the electrical connectors were drilled. Various small screw holes were drilled and tapped to mount the electronics parts.

O ring seals offer many advantages including simplicity, re-usability, and high pressure resistance. We reviewed manufacturer's literature to find the correct groove width and depth to achieve optimum O ring compression. We also researched different types of O ring materials, and selected EPDM as the most appropriate for use in water. Testing showed that proper O ring lubrication is important for ease of assembly, and that disassembly can be tricky because of the large size of the tube. The SCULL was tested for water tightness, and never leaked.

O-rings work so well to seal the housing ends, we thought they might work to seal the wires. The idea is to drill a hole for each wire, then drill part way through with a larger drill, leaving a cavity for the O-ring to sit in. The holes would be sized so the O-ring is compressed. A plate is needed to retain the O-ring (Figure 3). We drilled holes for each motor and tether wire, and counter drilled them to accept the O-rings. Each set of four motor wires has a retainer plate held in with a screw. A silicone-based grease is used to lubricate all the O-rings, to make assembly easier (Figure 4).

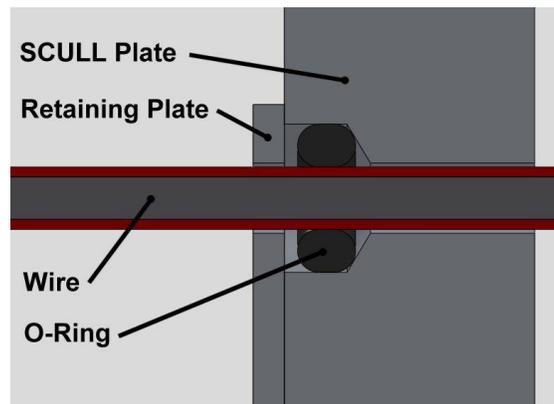


Figure 3

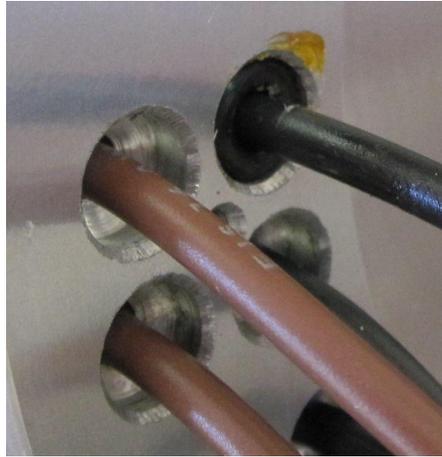


Figure 4

## Control System

We decided early on that Babs would have single operator control, using a commonly available video game controller. Some Internet research revealed that the Sony PlayStation2 controller had been reverse-engineered by the robotics community, and interface software was freely available. The Sony controller uses an SPI serial interface that is widely implemented in common 8-bit microcontrollers. We decided to use a serial data transmission method, since we could also send telemetry data up to the shore from Babs on the same serial interface.

Since we had no clear idea which controls on the PlayStation2 controller should be assigned to each control function on Babs, we decided to make the assignment of controller buttons and joysticks to ROV functions entirely configurable, using the controller itself to navigate a set of configuration menus displayed on a four-line text display (Figure 5). The display shows the telemetry data while operating.

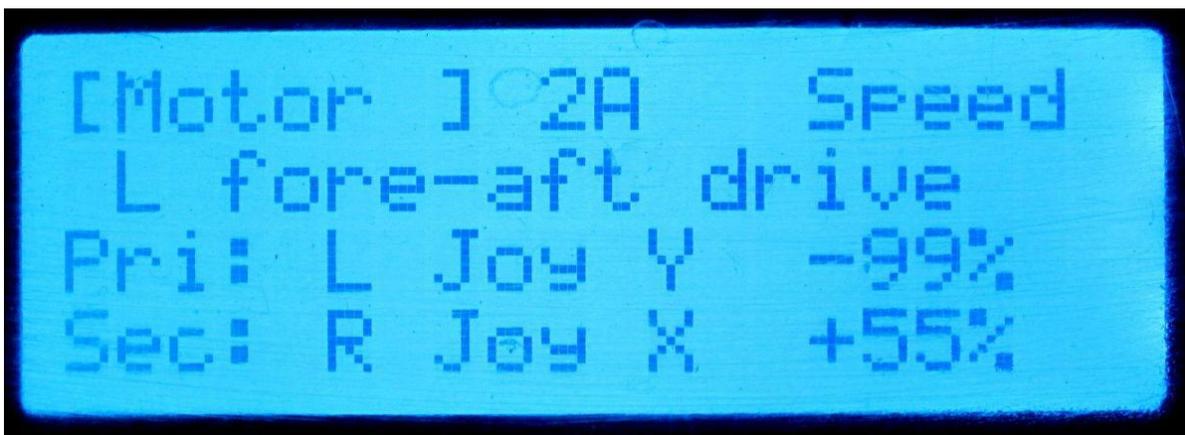


Figure 5

Since only onboard video may be used to drive the ROV, we worked to make the video signal as clean as possible. A pair of balanced differential signal drivers on the backplane drive the video and audio signals up the signal tether cable, and matching differential receivers are used to convert these signals back to single-ended form for connection to both the officials' and the driver's displays.

We decided that the circuitry should be packaged in a compact, cubical space. We designed a backplane that could hold up to five two-channel motor controllers. An aluminum card cage was designed to conduct heat from the motor controller transistors, through heat sinks to one side of the card cage, then to the SCULL end plate.

The control system has been integrated into a set of three circuit boards: the RTXA transmitter, the RRXA receiver/backplane, and the RSCA dual motor speed controller (figure 6). The transmitter resides in a plastic box on the shore. It has a signal tether connector, a controller connector and two pairs of audio/video connectors. A four-line LCD display shows the telemetry data while operating, or the configuration menus while modifying the controller parameters. A microcontroller programmed in C communicates with the PlayStation2 controller via an SPI serial interface and with the ROV using an RS-485 bidirectional differential serial interface.

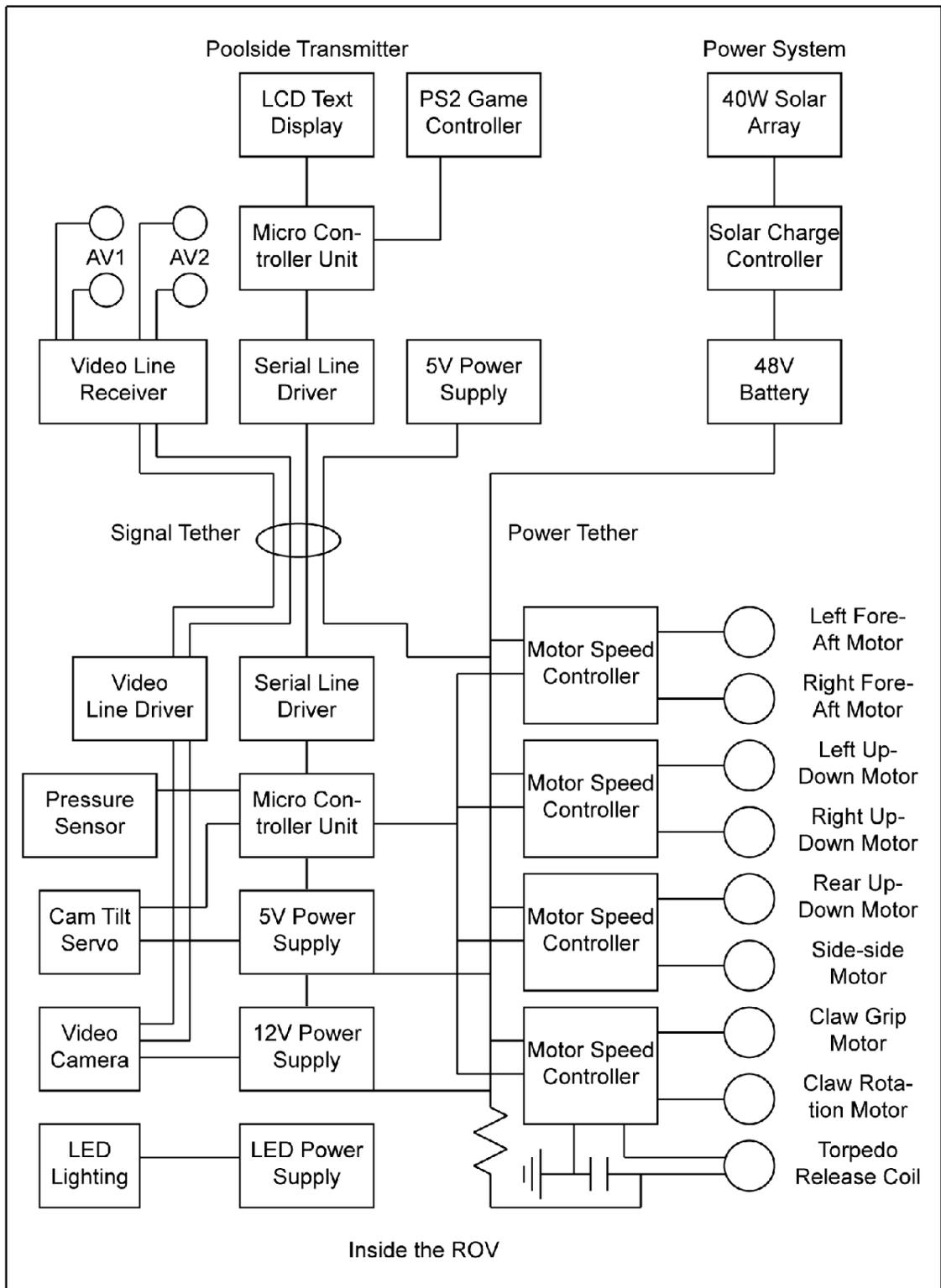


Figure 6

The power tether is a 16 AWG zip cord that carries 48V DC power from the battery box to the ROV. The signal tether that connects the ROV to the transmitter box is a standard Cat-5e Ethernet cable. One pair carries low-current 48V DC power up to the transmitter. Another pair has bidirectional RS-485 asynchronous serial data. The last two pairs carry audio and video signals from the camera to the display.

The receiver/backplane card is bolted to an aluminum card cage. It connects to the signal tether, the 48V power tether, the video camera, the camera LEDs, the camera rotation servo, and the telemetry signal transducers. The motor speed controller boards connect to the backplane power and signals via a special right-angle plug-and-socket connector and to the motors via screw terminals (Figure 7).



Figure 7

The motor speed controller system operates multiple motors in a time-sharing mode, modulating each with from zero to 25% duty cycle to permit operation of four 10 Ampere, 12V motors at once with a 10 Ampere, 48V power supply.

A PIC 18F4523 microcontroller is used in each of the transmitter and receiver boards to perform all necessary tasks by executing programs written in the C language. The schematics and software that is running on the microcontrollers is available in source code form on the ROVotron website: <http://www.rovotron.com/>

The control receiver board was outfitted with a switching LED current regulator to provide for up to eight LEDs wired in series at 700 mA current. The camera/light assembly is mounted on a servo, so we can tilt the camera through the full 180 degree range from straight up, forward, and straight down, and the light follows the camera motion. Vision is excellent.

## Power

Babs runs on solar power, stored in four 7-Ah sealed 12-volt lead-acid batteries. A 40-watt solar panel is set up for full sunlight. A plastic box holds the batteries, charge controller, charge/run switches, and system fuse. The batteries are connected in parallel when the switches are set to “CHARGE”, and they are wired in series when switched to “RUN” (Figure 8). The solar panel and ROV are connected to the battery box wiring with paired Anderson connectors, which are keyed differently so they cannot be connected wrong. The batteries provide nominal 48-volts and the fuse is rated at 15-amps, so the maximum power the ROV can use is 720-watts, well under the 1700-watt maximum allowed. The box also includes a digital panel voltmeter, to monitor charging voltage, and allow quick checks of the voltage of each battery.



Figure 8

## Manipulator

To meet the requirements of the mission, we figured out early on that a somewhat sophisticated manipulator was needed. We decided that Babs needed a manipulator that could both grip, and rotate. To make it easier to control, we wanted to be sure that the gripper could rotate freely without having to worry about tangling wires. We wanted to find a design that used the same pre-sealed motors that were used on the thrusters. While this meant any mechanical reductions would be submerged in water, it eliminated the need to construct reliable seals.

The final configuration for the manipulator is shown in Figure 9. Rotation of the gripper uses a worm gear reduction from the motor shaft to a 60-tooth gear attached to the main body. Clamping force comes from a winch, which is driven by a worm gear reduction using a 36-tooth gear. Fishing line connects the winch to both gripper arms. Because this line is concentric with the gripper rotation, the gripper may be rotated many times without affecting gripping ability (although the line may become twisted, it will still function properly). When the line is let out, the gripper arms are forced open by torsion springs at the base of each arm.

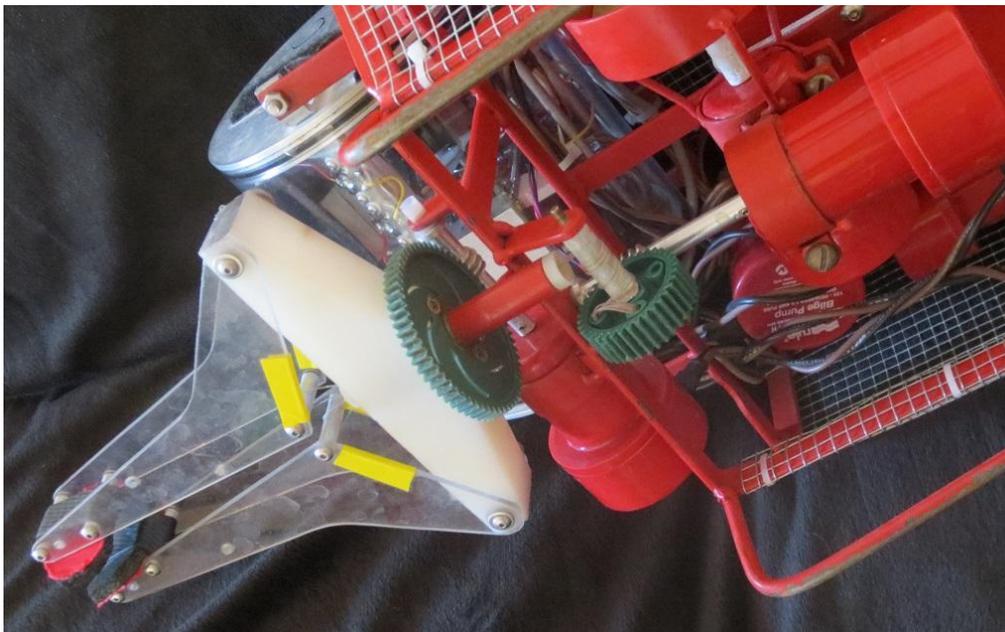


Figure 9

## Operation

The entire system is shown in Figure 10. The only components needed for operation are the ROV, the surface control box (transmitter), PS2 controller, battery box, and television monitor. Once all of the components are set up properly, Babs can be powered up and start running immediately.



**Figure 10**

The configuration of the controller can be changed quickly on the fly to suit the preferred driving style of the operator. After testing several controller configurations, we concluded that the configuration shown in Figure 11 gives a good level of control to the driver. Having all operations on a single controller allows all maneuvers to be performed by one person.



**Figure 11**

## Testing

To prepare for the Rescue from the Sargasso Nebula mission, we first had to build a nebula prop. The nebula was described in the challenge as a series of plastic strips that hang down in the mission area to cause confusion and make driving difficult. Having never driven in this kind of environment, we decided to construct a mockup of the competition nebula and see how it affected our ROV's ability to drive.

Our mockup nebula is pictured in figure 12. We constructed it using 3.5mil plastic painter's sheeting, separated into rectangles and cut into strips. Each strip was 3" wide and 5' long, weighted with a galvanized nail threaded through the end. The overall assembly was approximately 6' long and 6' wide, quite a bit smaller than the actual nebula used in the competition.



Figure 12

To prevent the nebula from getting caught in our propellers, we added shrouding to the sides of the ROV. We did tests during daylight and night time to see how visibility was affected, and it was clear that visibility was going to be a huge problem. It also became obvious that getting lost or stuck in the nebula was going to be a big issue for a lot of the ROVs. We attempted a design modification (Figure 13) that was meant to allow the ROV to slide between strips of the nebula easily, but it did not prove to be effective. In the end, we decided that careful navigation and cable management was the best way to deal with the nebula.

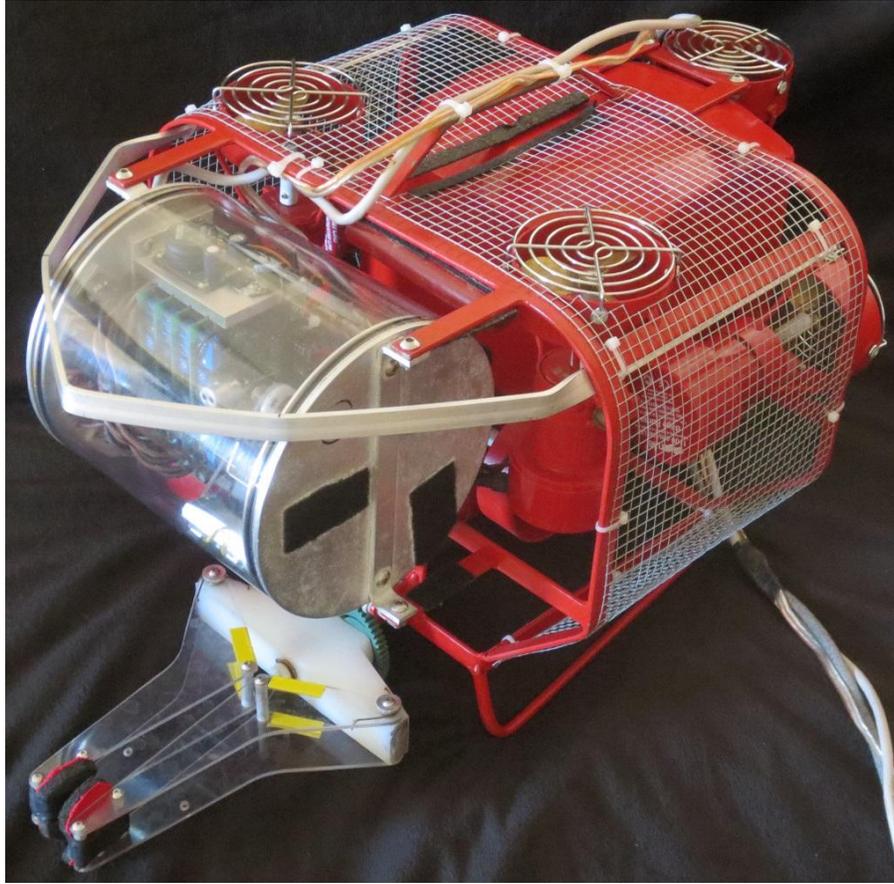


Figure 13

## Acknowledgements

We would like to thank the Jones family and the Moeller family for the generous use of their swimming pools, and APASE for sponsoring this competition. We would especially like to thank the many volunteers that make it possible.