Technical Report
Falmouth Academy ROV Team

The Design and Construction of a Remotely Operated Vehicle

Rachel Allen, Mike Kowalski,
Oliver Moore, and Joey Smith

Mentors: Mr. Ben Allen, Dr. Albert Bradley,
and Mr. Peter Conzett

Falmouth, MA
June 11, 2004

Marine Advanced Technology Education Center
3rd Annual ROV Competition

1 Abstract

The purpose of this project was to design and build an underwater ROV for the annual MATE ROV competition. The vehicle needed to be able to complete the 7 missions that were part of the competition, including having a functioning underwater camera, a manipulator for the deployment and retrieval of objects, and maneuverability.

The group started out by visiting different companies in Falmouth that build underwater vehicles, to understand more about their structure and construction process. Following the visits, the group began to plan and design our own ROV. Initially, the shape of the vehicle, along with the type, shape, and placement of the thrusters were considered. The team then began to design the motor housings to waterproof the motors, choose an efficient propeller, choose a camera, and start to construct the manipulator. This moved the group into the construction phase, in which the components of the vehicle were individually constructed. Having the individual components working separately, with modifications from the designs occurring daily, the team put the different parts together on the chassis, and began to test the vehicle.

The completed ROV is about .46 m wide, .38 m tall, and .56 m long. It can operate at a depth of 5 m, and has a tether about 18 m long. Its four motors are positioned such that it can move laterally, horizontally, and vertically, and can change its forward direction (yaw). It has a two-function manipulator and a collecting basket, as well as an underwater camera and a light. These capabilities should enable it to complete the missions for the MATE ROV competition.

2 Background

2.1 ROVs in National Marine Sanctuaries

Researchers from the National Oceanic and Atmospheric Administration performed the Sanctuary Quest Expedition with the aid of the National Facilities Engineering Service Center's Phantom ROV. This mission went to five National Marine Sanctuaries along the West Coast. John McDonough, the expedition coordinator, described the three primary goals of the mission. "One is to learn a little more about habitat. This is in depth of the sanctuary that is below SCUBA depth. The other goal is to learn a little bit more about some of the perhaps human use of the sanctuaries themselves. The third thing is to continue on with some of the ongoing monitoring efforts that have been occurring in the sanctuary" (sec. 1). The ROV was used mostly to help them characterize the underwater habitats by taking video data at depths below those that humans can reach. "We're going to be using a variety of tools and instruments during this expedition, but the primary tool is going to be the remotely operated vehicle, an ROV. You put it down in the water below SCUBA depth and you get visual imagery from it" (McDonough, sec. 3).

The Sanctuary Quest Expedition team studied the Channel Islands, Monterey Bay, the Gulf of the Farallones, Cordell Bank, and the Olympic Coast in an expedition from April 24 to June 20, 2002 ("Mission Plan," sec. 2). At Channel Islands the ROV was used for "groundtruthing" the data collected by sidescan sonar by collecting visual images of the underwater habitat, as well as recording the remains of the vessel *Pac Baroness*, lost in 1987. At the Gulf of the Farallones and Cordell Bank, however, the ROV was used to collect visual imagery of the invertebrate and fish communities found within the sanctuary ("Mission Plan," sec. 4).

The ROV used in these missions was the Phantom ROV, provided by the National Facilities Marine Service Center. It is capable of diving to about 600 m, can move horizontally, laterally, and vertically, has a forward thrust of 93 kg, weighs about 148 kg, and has assorted video and still cameras (see Photo 1). Various other instruments, such as a three-function manipulator, sonar, and an altimeter, add to the capabilities of the ROV ("Phantom ROV").

With the research done by this Sanctuary Quest team, more is understood about the five sanctuaries along the western coast of the United States. Each sanctuary is unique for its underwater habitat. The Channel Islands are a breeding ground for many species of marine life. The Monterey Bay Sanctuary is used to help protect marine life. The Gulf of the Farallones, larger than Rhode Island, is home to many marine mammals and birds. Cordell Bank is a submerged island with topology that creates upwelling giving life to some of the most biologically productive areas on the west coast. The northern Olympic Coast Sanctuary has one of the most diverse marine mammal faunas, and is a necessary link in the Pacific flyway ("Marine Sanctuaries"). By studying the underwater habitats present in these sanctuaries with an ROV, the Sanctuary Quest Expedition added another level of knowledge to the protected sanctuaries on the west coast.

2.2 Companies in Falmouth that build underwater vehicles

During the first stages of the project, the team visited several local organizations that construct underwater vehicles professionally, in order to understand the basic make-up of underwater vehicles, what is essential to all underwater vehicles, and what types of techniques the professionals use that would be feasible for this project.

2.2.1 WHOI –ABE

Dr. Bradley, one of the primary engineers of the Autonomous Underwater Vehicle, ABE (Autonomous Benthic Explorer), spoke about its design and capabilities. He explained some of the essential capabilities of an AUV, as opposed to an ROV, including the ability to carry batteries and maneuver close to the bottom without hitting things and without human instructions. ABE uses techniques like having large propellers to increase thruster efficiency and having the center of buoyancy match the center of gravity so that it doesn't rock and roll. Dr. Bradley, an enthusiastic supporter of students in engineering, also suggested that on an ROV a large rotary seal would be easier to seal, to position the camera such that a compass on the vehicle would be visible, to have feedback sensors on the arm, or put it in front of the camera, so that its position is known, to expand the structure of the vehicle, so that the thrusters are inside it, and to have a flexible umbilical cord.

2.2.2 WHOI/ Hydroid

The vehicle REMUS, first designed and built at WHOI, now produced in the company Hydroid, Inc., was explained by engineer Ben Allen. REMUS, Remote Environmental Monitoring UnitS, is an AUV. REMUS has many electronic features that may or may not be useful, such as an internal compass that knows the earth's magnetic field, 4 methods of navigation, and various scientific sensor devices. REMUS uses sidescan sonar to make its images rather than cameras because the cameras depend on water clarity, while the sonar can produce data for detailed maps without requiring clear water. More useful, perhaps, is their technique of having the vehicle slightly positively buoyant, requiring it to keep moving forward in order to stay at its depth. In addition, the engineers are continually modifying their vehicle, changing the scientific instruments on it, or creating different versions for specific depths or purposes. Even though the techniques REMUS uses may not be as helpful in creating an ROV, the techniques used by the engineers may be more useful in our project.

2.2.3 Webb Research Corporation

Webb Research produces very specific types of data-collecting instruments, called floats. The floats are placed in the oceans around the world, and change their buoyancy by changing the size of an oil bladder. They then go down 1 mile deep during the course of 10 days, collecting data on the conductivity, temperature, and pressure of the water. When they resurface, they send the data via satellite to the scientists monitoring them. With the data taken by almost 1,000 of these instruments around the world, scientists can monitor the temperature, conductivity, and pressure of the water, as well as watch the currents at work. In addition, Webb Research builds an AUV called a glider that uses changes in its buoyancy, located in its front portion, to lead it on long gliding dives up and down, in the manner of hang gliders. Because the energy required for this instrument to change its buoyancy is very small, the gliders will be able to last for about 30 days in the water, without changes in the batteries. The glider takes data on conductivity, temperature, and density, and can calculate the depth using sonar. As with REMUS, the instruments on these vehicles can be changed. From the Webb glider, it seemed that the team could get very specific advice on how to create the best buoyancy for our ROV, but the other techniques used by these engineers are less useful.

2.2.4 Benthos, Inc.

Benthos has been building ROVs for 20 years, though it is not their main function as a company. In describing the ROV that they had presented, the engineers had suggestions for us on how to construct an ROV. They suggested having a simple manipulator, with only necessary functions. They suggested allowing the camera to tilt up, down, left, and right to allow more visibility, and giving the ROV a slightly positive buoyancy in order to be able to retrieve it if anything happened to it, whereas the tether should be neutrally buoyant. In consideration of our price limitations, the engineers suggested a milk crate as the frame of the ROV, with insulation panels, PVC pipe, or pingpong balls as flotation. From their ROVs, we could determine that a useful configuration of four thrusters was to have two going forward, side-by-side, one going up and down, and one side to side. The Benthos engineers suggested using everyday materials to make our ROV for familiarity, simplicity, and economical reasons.

3 Purpose

The purpose of this project was to design and build an underwater ROV according to the specifications set out by the MATE competition, in order to compete in the Annual MATE ROV competition.

4 Methods/ Results

4.1 General Overview of Stages

In retrospect, the time spent on this project can be broken down into separate categories based on the different types of work done. The initial part was spent gathering information about underwater vehicles, the visiting stage; the second part was spent planning and designing the ROV; the third part was spent in construction; and the final part of the project was spent testing the vehicle. The stages were not evenly divided and often overlapped, however most of the work done fits into one of these categories.

4.1.1 Visits

Visits to local engineering companies were made at the start of the project, in order to learn more about the type of work done with ROVs and AUVs, and the techniques that are used in constructing them that could be relevant to this project. The team visited the Woods Hole Oceanographic Institution Applied Ocean Physics and Engineering Department, Hydroid, Inc., Webb Research, Corp., and Benthos, Inc. The visits consisted of a tour of about 1 ½ hour during the workday of the companies, with all four team members present. In addition to studying the vehicles created by these engineers, the team looked for elements used in these vehicles that would need to be considered in the creation of our ROV.

4.1.2 Design and Construction

The design stage started right after the visits were completed, and extended through the construction period. During the construction period, as difficulties were encountered, decisions were made based on the situation, and the design was modified accordingly. A photo of the ROV can be seen at the end of the report.

The basic problem presented to all ROV teams was getting a battery at the surface to run a vehicle underwater. We chose DC motors to be the key link between electrical and hydrodynamic power. The motors had to be on the vehicle, so the first step is to get battery power down to the vehicle. We accomplished this with a 15-conduit tether made mostly of 18- and 22-gauge speaker wire. Given our available power of about 300 watts, we chose motors of appropriate rpm and wattage (Table 2). These DC motors would not work very long open to the water, so we had to machine watertight housings for our motors that had stationary seals and a dynamic shaft seal. Given the rpm and torque of the motor, we chose propellers that would yield high thrust and fair efficiency. The motors needed to be attached to some sort of frame so we built a box-like, strong, easily modified frame of steel and later fiberglass. At depths of up to 5m, inside structures, and with potentially reduced light, we needed a camera on the vehicle; our camera has built-in LED illumination and can see in color. We also want some kind of manipulator of marginal dexterity for work underwater. Wire mesh surrounds the vehicle and protects our propellers. Motor controllers and switches let us control our machine.

4.1.2.1 Chassis

The chassis consists of fiberglass angle-bars arranged in two rectangles, one at the center and one at the rear of the vehicle. The rectangles were connected at their corners by four parallel angle-bars. The lateral thrusters are connected to the middle vertical L-bars with hose clamps and wooden braces. The vertical thruster is connected to wood placed between the middle vertical L-bars, and the horizontal thruster runs underneath the lateral thrusters. The camera is placed at the top center of the forward rectangle of the chassis, and the manipulator is just below it. There is a basket placed in front of the vertical thruster that can be accessed by the manipulator. The tether is attached to the vehicle at the top center of the rear rectangle. The entire chassis is wrapped in wire mesh to protect the propellers.

4.1.2.2 Thrusters

The motor chosen to use in this project was the Maxon motor 2260 885 51.216-200. The team decided which motor to choose based on the speed-torque curves created for several motors from Maxon and Micro Mo. The graphs compared the rpm of the motors, the input and output power, the power efficiency, and the current draw, all compared to the motor torque. These graphs were based on specifications from the motor catalogues, and were varied depending on the input voltage that we intended to supply the motors with. For example, we had to create a new speed-torque curve for the Maxon motor 889 that we considered using because it normally operated with 48 volts, and we are limited to 12 volts. The motor we are using is a 24-volt motor that we are running at 12 volts, so we were also required to make the same adjustments with the Maxon 885 (see Figure 1). We also compared the size of the motors, their weight, the torque limit, their max and min rpm, torque, and current draw, and the motor wattage. We knew that we wanted four motors, each drawing at maximum about 85 watts. We considered a number of motors from Maxon and Micro Mo, including 70, 80 and 90-watt motors from Maxon, and 85, 88, and 105 watt motors from Micro Mo. We had narrowed our choices down to a few motors when we found four used Maxon 885 motors in the WHOI OSL scrap box that were unusable for the professionals and would have otherwise been discarded. Because the Maxon 885 was one of the motors we were considering, we chose to use the ones that we found. Therefore, the price of the motors, which may have been a significant issue in deciding which ones to choose, was not relevant. Figure 1 shows the performance characteristics for the motor chosen. It is estimated, based on tests on the motors, that at full power they are operating at about 500 mNm torque, 5 Amps, 450 rpm, and 40% efficiency. The chosen motors were then tested with various props to determine the most efficient prop based on the force of the propeller, the amperage drawn, its predicted durability, and its size (see Photo 3). The model airplane props that were chosen have diameters of about .2 m and .3 m, are durable, have pitches of 20 cm/rev (8 in/rev) (see Table 1). Designs for the motor housing were then drawn up in order to effectively seal the thruster, allow for a rotating shaft seal with minimal friction, and prevent the motors from rotating within the housing. Construction on motor housings began quickly, but required careful assembly to get the end caps to match the cylinders. After the four motor housings were completed, tests were performed with the motor housings placed in water of shallow depth for a short period, shallow depth for a long period, and a depth of 5 m for an extended period. This test was performed with the first completed versions of the motor housings, as well as with the motor housings with modifications for electronics and other additions. The final stage consisted of securing the motors inside the functioning housings, attaching the propellers via couplings on the shaft, attaching the housings to the chassis with blocks of wood and hose clamps, and testing the power supply wires.

4.1.2.3 Camera

A camera was chosen because there was a waterproof underwater camera available that ran on 12V, drew about 110 mA, had LED lights that provided light at low power, had a small, flexible tether, and could be borrowed from WHOI for use in our project. The camera is the CVC-625WP from Speco Technologies. It has an automatically controlled shutter speed of 1/60 to 1/100000 s, the LEDs provide 1 lux, it has 350 lines of resolution, images in color, and has a 3.6 mm fixed focus lens. This color camera provided a better image than any camera that we could feasibly buy, so the choice was easy to make. The camera was affixed to the front end of the chassis, in the middle of the upper bar, such that it showed the arm functioning, as well as the area in front of the ROV.

4.1.2.4 Arm

We bought a kit online to build a robotic arm with 5 degrees of motion. The construction of this air-functioning, but not waterproofed, arm greatly helped the planning stage of the arm, which was wavering between building an arm from scratch, buying something, or adapting something to suit our purposes. After the construction of the dry arm, adaptations were made to it that included new, waterproofed, DC motors, while retaining some of the same structure of the purchased arm. The completed arm has two degrees of motion: a pinching claw and a bending elbow. It is controlled with on/off power switches via the tether, and is attached to the chassis in the middle of the lower bar in the front of the ROV. The elbow lifts the arm up so that it can drop acquired objects into a basket that is part of the ROV.

4.1.2.5 Motor Controllers

After much trial and error assembling preliminary circuits, we decided on a control system whereby a joystick controls surge, sway, and yaw while another, separate adjust controls heave. We worked with Dr. Bradley to design and construct the circuitry necessary to convert joystick motion into a pulse-width-modulated signal to drive the motors. With some practice, this configuration should allow one person to easily control the movement of the ROV.

4.1.2.6 Tether

The tether consists of 8 strands of 16-gauge wire, 1 each input and output for the thrusters, the camera cable, and 6 strands of 22-guage wire, 1 each input and output for the motors in the arm. The wires were bundled together at the back of the ROV and given slightly positive buoyancy so that they do not interfere greatly with its movement. They were bound loosely so as to have the maximum amount of flexibility in the tether. The wire mesh around the vehicle prevents the tether from fouling the propellers.

4.1.3 Testing

After the separate parts were fixed to the chassis, the ROV needed to be tested. It was driven in a family swimming pool, so it could not go to 5 m depth, but the housings had already been tested at that depth. Each of the team members needed to be able to control the ROV and the arm, however we needed to choose who would drive the ROV and control the arm in the competition with the greatest precision. Models of the competition props aided our practice.

5 Analysis

5.1 Design Rationale

5.1.1 Chassis

Initially, the shape of the vehicle, along with the type, style, and placement of the thrusters were considered. The team first decided to have three cylindrical canisters creating a triangle as the form of the chassis, two on top providing flotation and the bottom allowing room for electronics and stability. However, as the planning stage progressed, it became clear that having an ROV that would not stay straight up sitting on a table was not a good idea, and the 3 canisters became 4, creating a cubical shape for the ROV. During construction, it was realized that the lower canisters were not needed for anything, and that the use of foam as flotation instead of sealed PVC pipes would be more manageable, so the chassis became a simple combination of a square of steel angle-bars in the front attached to a square in the back by straight bars in the top corners, and one in the middle of the bottom, along with two vertical angle-bars in the middle of the ROV. Steel angle-bars with holes along them were chosen because they provide good strength per unit weight, and the right-angle shape allows more space for other pieces to be affixed to it. Later, we replaced the steel with fiberglass for less weight and greater rigidity. Crosspieces were used to brace the corners of the squares so that the chassis of the ROV would hold its shape.

5.1.2 Thrusters

We decided, given the reef environment, to build an ROV with good agility and fair power. We have no ballast control and no control surfaces (such as might be found on AUVs and military submarines), so motor function controls all movement. We decided on a four-motor configuration: two parallel that could push the craft forward and reverse, one vertically oriented, and one laterally oriented. This gives us direct control of motion in the three axes, as well as control over yaw. We do not have control over pitch or roll, so the flotation was arranged so as to maintain a stable, level orientation.

We saw two main options for motors: pre-waterproofed bilge pumps or DC motors for which we would have to build housings. In the interest of power efficiency, we chose DC motors. Bilge pumps get their thrust from pushing a small volume of water at high velocity, while DC motors with propellers send a large volume of water at lower velocity. Energy put into the ROV is ½(mass)*(velocity^2). Energy put into the stream of water is calculated by the same equation. Ideally, the greater the mass of water moved compared to the mass of the ROV and the lower the velocity of that water compared to the velocity of the ROV, the greater the efficiency. In addition, by having a small volume of water moved at a high velocity, we would risk losing efficiency by creating turbulence in the water with the small amount of high velocity water. Given any DC motor and its geared-down counterpart, the geared-down motor can drive a larger diameter propeller (pushing a larger volume of water) at a lower speed. We could have geared down the motors we used, but decided it would be easier to use what we could find. Furthermore, at some point the diameter of the propeller becomes prohibitively cumbersome.

5.1.3 Camera

In order to complete the missions, we decided that the camera we used would need to be a simple, small, black and white camera with decent resolution. It would have to be an underwater camera, or we would need to find some way to waterproof it. In addition, it needed to use less than 2 amps of power. We needed a camera that could adapt to low-light conditions or had built-in lights.

5.1.4 Manipulator

The missions require that we be able to manipulate objects underwater with some dexterity. A simple shovel or fork would be the bare minimum. We decided that a claw would be more versatile. We also chose to add at least one joint, an elbow, so that we could control the orientation of the claw relative to the object. At this point we saw two options: fabricate an arm from geared-down DC motors, or buy a ready-made one. We found a some-assembly-required arm on-line at a reasonable price. We bought and built it, but still needed to waterproof it. Given the motor type and housing, this was not feasible. So we have a hybrid arm: most of the structure, function, and shape is adapted from the purchased arm, while the motors, which we waterproofed, are from another source and adapted to the purchased arm. The arm has an elbow and claw and is controlled by simple on/off switches at the surface.

5.1.5 Motor Controllers

We could control the motors with simple on/off switches. While this works well enough, we thought that a more finely controllable ROV would be a significant improvement. The main benefit is that with finer control, the arm doesn’t need to be as dexterous; in addition, the ROV would probably perform better in confined areas. We wanted a motor controller that could give us performance from full reverse, gradual to stop, gradual to full forward. The intention for the regional competition was to have four switches, one for each motor. The switches would determine reverse, off, and forward. Additionally, a knob, which turned a potentiometer, for each motor would determine motor speed. The system was neither functional nor reliable enough for the regional competition, so we reverted to simple switches with no speed control. After the regional, we worked more under the guidance of Dr. Bradley who helped us design and troubleshoot the circuitry for a joystick which controls surge, sway, and yaw. Heave is controlled separately. This joystick turns potentiometers varying the control signal for pulse width modulation circuitry.

5.1.6 Tether

The tether is the ROV’s lifeline, carrying power and signals. Three main components need to be a part of the tether: wires for the manipulator, the video camera, and the motors. As of now, each motor has two 18 m 16-gauge wires for power and control. 16-gauge wire was chosen because it allowed about 10 amps, our required current, through the wire, with minimum resistance to the power, high flexibility, and low drag. The manipulator has two motors and therefore two pairs of 22-gauge wire. The camera came with a coax cable. The tether was made approximately neutrally buoyant by attaching small strips of foam incrementally along the length of the tether, so as not to encumber the ROV’s movement. The floatation was added to the tether depending on the length of the tether, to provide variable buoyancy. The tether closest to the vehicle was as close to neutral as possible, but the tether that was farther away was more positively buoyant, to keep it on the surface and out of the way of the vehicle.

5.2 Vehicle Performance

The ROV performance is primarily determined by the thrust and placement of the thrusters, in combination with the resistance provided by the shape of the vehicle, its stability, and the tether. Our vehicle is quite large: 46 cm wide, 38 cm tall, and 56 cm long, and it requires floatation to keep it neutrally buoyant. However, the large size of the vehicle allows us to house four thrusters with 20 to 22.25 N of thrust each. The large frame size also allows the thrusters to be placed far enough from each other to provide large torque and thus a small turning radius. Because the tether that provides power to these thrusters is composed primarily of 18 and 22-gauge speaker wire, it is flexible enough not to hinder the vehicle significantly. The torque of the vehicle, calculated by multiplying the force of the forward/ reverse thrusters (one forward and one reverse, with the reverse thruster at 75% of the forward thruster) by the distance from the thrusters to the center of the vehicle, the turning radius, was about 4.5 Nm. The stiffness of the tether was calculated by measuring the effect of a certain weight on a specific length of tether, and was about 0.017 Nm. The ratio between the torque of the vehicle and the stiffness of the tether provides the stiffness ratio, which was about 260. The higher this ratio, the better the vehicle maneuverability, and the lower this ratio, the greater impact the tether can have on limiting the movement of the vehicle.

5.3 Challenge

5.3.1 Description

The biggest challenge faced by this team was creating watertight motor housings that can withstand the pressure of 5 meters and allow a watertight rotating shaft seal. In addition to the difficulties presented by the nature of the housing, the task was made more challenging because only one team member was allowed to use the equipment needed to make the housing (insurance reasons), and the task was very time consuming. Each housing, made of PVC pipe, needed to be about 30cm long and about 8cm in diameter. Both end caps required o-ring seals, and thus needed to be lathed to fit carefully with the cylinder. Because of the time required to construct a single part of the housings, the motor housings took a long time to be constructed. The time delay in getting them created set back the team’s time schedule, because little could be done without the thrusters. Furthermore, one of the four motor housings failed during initial testing and needed to be fixed. The other housings passed the initial tests, however the vehicle could not be operated without all four thrusters.

5.3.2 How it was overcome

This challenge was overcome by simple perseverance. Oliver, the team member who could work on the thruster housings, spent extra time in the lab working on them, while others continued to construct the chassis, complete the motor controllers, and wind the tether, so that we did not lose too much time. Once completed, the other team members began working with the functioning motor housings, attaching them to the chassis, while Oliver fixed the leaky one. The additional tests were performed during various times. The fact that the team members had different schedules and could not all meet to work together at the same time also made it more difficult, but this was overcome by regular updates of work done and problems encountered during free periods at school. Although there was no one huge problem encountered during the construction of the motor housings, as a whole, their creation has been one of the most difficult challenges this team has had to face.

5.4 Experience from the New England Regional Competition

5.4.1 Vehicle performance

At the New England Regional competition, we were generally pleased with our performance in the mission component. We were able to successfully tag the tube worm cluster and the mussel bed because of our capable manipulator and our maneuverability. Had we not dropped the patch while attempting to reach the leaky barrel, we think we might have completed that mission as well, because of our success with the tag. We were unable to locate the bell inside the U-boat because our vehicle was too large, and was blocked by unseen bars in the U-boat structure, and therefore could not complete the mission requiring us to read the inscription on the bell. We attempted to bring the line down to the towfish, however the first time we tried, the carabiner came out of the manipulator because there was too much tension on the towfish line, and the second time the line got caught in the exposed propeller of the vertical thruster. This entanglement required us to pull up the vehicle with the tether in order to remove the line. This broke the shaft seal of the thruster housing, and caused the motor to flood, but it continued to function at nearly full capacity for the remainder of the mission component. We successfully retrieved a rock from the collection in the reef by using our manipulator to pick it up, and brought it to the surface in the basket. We found, however, that with the weight of the rock added to the ROV, the vertical thruster had difficulty raising the vehicle. We also successfully retrieved a sample of the correct fish species using the manipulator and carried it to the surface. We additionally freed another species of fish by cutting its line that tied it to the bottom with our exposed propeller, which added the weight on the fish line to the weight of the vehicle. Overall, we received 50 points for our mission performance, however our mission time was shortened because we were required to retrieve the vehicle with the tether.

5.4.2 Lessons learned from the mission

Based on our performance in the pool, we found several changes that we needed to make to our vehicle. While our manipulator was dexterous, we found that it would be easier to work with if it were stronger. As it was, it performed well enough, but gave its operator difficulty because it could not always hold an object in its grasp due to slipping gears. We decided to modify the manipulator so that the gears would be able to bear the load. Additionally, our difficulties in finding the U-boat bell made us decide to down size our vehicle and add a motor to the camera so that it would be able to tilt up and down. While we were unable to reduce the size of our vehicle significantly due to the fixed size of our thrusters, we added a motor to the camera, and also moved it from the front of the vehicle to the center to allow us a larger field of vision. In order to protect our propellers, we decided to encase our vehicle with chicken wire so that objects will be unable to interfere with the propellers.

5.4.3 Lessons learned from the judges

Based on our interactions with the judges, we learned that our vehicle was lacking a few required safety measures. They also pointed out that our steel frame could have been more rigid in order to provide more structure for our large vehicle. Our method of securing the floatation to the vehicle was primarily bolts and wire ties, often reinforced with duct tape, and was neither attractive nor professional. We decided to adjust our circuitry so as to include the required fuses, and change the chassis of the vehicle to fiberglass because of their comments.

5.4.4 Observations

At the competition, we found several areas in which our vehicle varied significantly from many of the other vehicles present. For example, many of the other vehicles used PVC pipe for their chassis structure, and used modified bilge pump motors to provide thrust. We also noticed that several teams had specific appendages for certain tasks, such as a rod in which a carabiner could be placed for the retrieval of the towfish. The rod allowed the vehicle to push the carabiner against the towfish to attach the line, and then back away from the towfish and release the carabiner. Because of the simplicity of such an appendage, we may decide to add one to our vehicle based on further tests with our current manipulator.

5.5 General Troubleshooting techniques for technical problems

Depending on the type of problem, the team had different techniques for figuring out how to solve it. However, for most problems, we would start out by determining what component was malfunctioning. The next step involved deconstructing the component to determine why it was not working. If the part were not working because of a construction error, we would reconstruct it slowly, testing each part as we went along. If it were not working because a part was broken or missing, we would fix or replace the part, and then reconstruct the component slowly, again testing each part. With this general process, most mechanical or electronic problems could be fixed efficiently, and without losing the organization and order the original component had.

5.6 Lessons learned

One of the primary lessons learned during this project is that one can only plan so much. The team probably spent too much time in the planning stage, trying to figure out little details that ended up being changed anyway. Much of our planning was necessary, so that we knew what we were doing and what our goal was, and so we could make the big decisions, like what motors and camera to use, however beyond that, the planning was not very useful. What was more useful in developing the ROV was to do some construction, and then see if more things needed to be planned out.

Additionally, the team gained skills, which should be useful to engineers. Oliver became quite skilled at turning PVC on the lathe and creating watertight seals, and Mike fully understands the electronics of the motor controllers, along with being able to construct working ones. All of the team members have learned about improvising things for our uses, though they may not serve their intended purpose, such as using hose clamps to secure the motor housings.

5.7 Future improvements

In the future, the team might adjust the motor controllers so that the electronics are partly on the vehicle. Power would be sent to the ROV on two wires (10-gauge) and distributed at the ROV, while the control signals to do so would be sent to the ROV on four pairs of 22-gauge wire. This change would result in lower tether mass, lower tether cross-sectional area, and greater tether malleability. It would also allow the potential for auxiliary power to be stored on the ROV.

Other improvements might be creating a smaller frame for the vehicle, so that it could more easily fit into the small spaces. As it is, it barely fits through a hole with a .6 m diameter. This would be difficult, however, because the size of the vehicle is restricted because of the size of the thrusters.

6 Conclusion

The purpose of this project was to design and build an underwater ROV for the annual MATE ROV competition. The vehicle needed to be able to complete the 7 missions that were part of the competition, including having a functioning underwater camera, a manipulator for the deployment and retrieval of objects, and maneuverability.

The ROV has four Maxon 80 watt motors that are enclosed in motor housings made out of delrin and UHMW plastic and PVC pipe. The motors are supplied with power through an 18 m long tether with 16-gauge speaker wire. The power supply to the motors is regulated by motor controllers, which have a forward reverse switch and a pulse-width modulator to control the voltage. The power supply is limited to 12 volts and 25 amps at any one time. The two forward-reverse motors and the horizontal motor have propellers with a .1 m radius, and the vertical motor has a propeller with a .15 m radius. The ROV has a manipulator with elbow, wrist, and grip motions. The manipulator can also place acquired objects in a basket on the ROV. The camera, placed on the forward upper part of the ROV, shows the manipulator, as well as the area in front of the ROV. It has a light to assist with visibility, and it is supplied with power and provides output through a small tether. The power for the manipulator is controlled at the surface, and supplied through 6 22-gauge wires. The completed ROV is about .46 m wide, .38 m tall, and .56 m long. It can operate at a depth of 5 m, and has a tether about 18 m long. Its four motors are positioned such that it can move laterally, horizontally, and vertically, and can change its forward direction (yaw). These capabilities should enable it to complete the missions for the MATE ROV competition.

7 Acknowledgments

The Falmouth Academy ROV team, consisting of Rachel Allen, Mike Kowalski, Oliver Moore, and Joey Smith, would like to thank the numerous individuals and organizations that helped and supported us. Hydroid, Inc., Webb Research Corporation, and Sippican, Inc. all supported our project with a generous financial donation. In addition, Hydroid, Inc., Webb Research Corporation, and Benthos, Inc. gave us tours of their facilities and research. Falmouth Academy also helped with the funding for our project. The Woods Hole Oceanographic Institution Department of Applied Ocean Physics and Engineering allowed us to use their lab space and tools for the construction of the ROV. Our teacher Peter Conzett allowed us to construct the ROV for our senior major effort project, and helped us to combine the competition with the format of a major effort. Dr. Albert Bradley provided us with guidance in the planning of the ROV, and helped with the electrical portion of the project. Craig Johnson assisted with the machining of the parts that needed to be custom made, and Ben Allen provided guidance in the design and construction of the ROV.

8 Bibliography

Allen, Ben. Woods Hole Oceanographic Institution. Personal Interview. Oct. 31, 2003.

Bradley, Albert. Woods Hole Oceanographic Institution. Personal Interview. Oct. 31, 2003.

Marine Sanctuaries. Jan. 14, 2003. National Marine Sanctuaries. Apr. 22, 2004 <http://sanctuaries.nos.noaa.gov/oms/oms.html>.

Niewiad, Kat. Webb Research Corporation. Personal Interview. Nov. 7, 2003.

NOAA Ocean Explorer: Sanctuary Quest: Background. May 2, 2003. National Oceanic and Atmospheric Administration. Apr. 22, 2004 <http://www.oceanexplorer.noaa.gov/explorations/02quest/background/plan/plan. html>.

NOAA Ocean Explorer: Interview with John McDonough. May 2, 2003. National Oceanic and Atmospheric Administration. Apr. 22, 2004. <http://www.oceanexplorer.noaa.gov/explorations/02quest/background/plan/media/O2quest_jmcd_intrvw.html>.

Phantom ROV. Nov. 14, 2001. National Facilities Marine Service Center. Apr. 22, 2004 <http://www.nfesc.navy.mil/ocean/esc50/vesveh/phantom.htm>.

Zentz, Peter. Benthos, Inc. Personal Interview. Dec. 6, 2003.

Photo 1: Phantom ROV ("Phantom ROV")

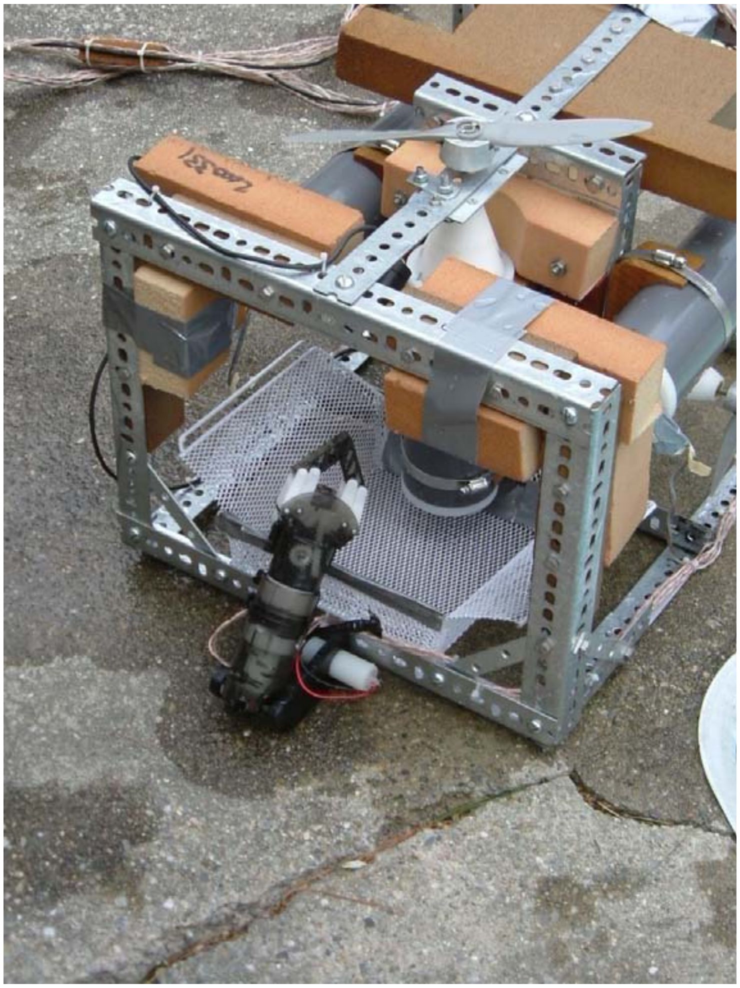


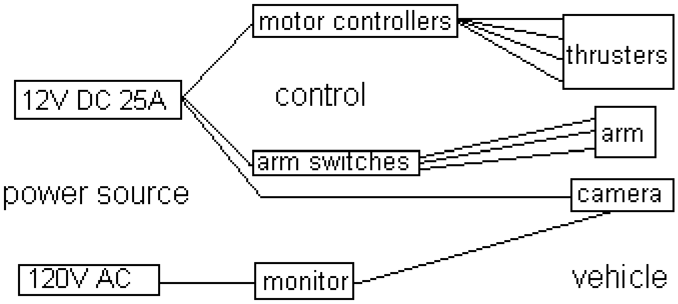
Photo 2: Falmouth Academy Team's ROV as of the Regional Competition

Photo 3: Propeller Testing Set-up

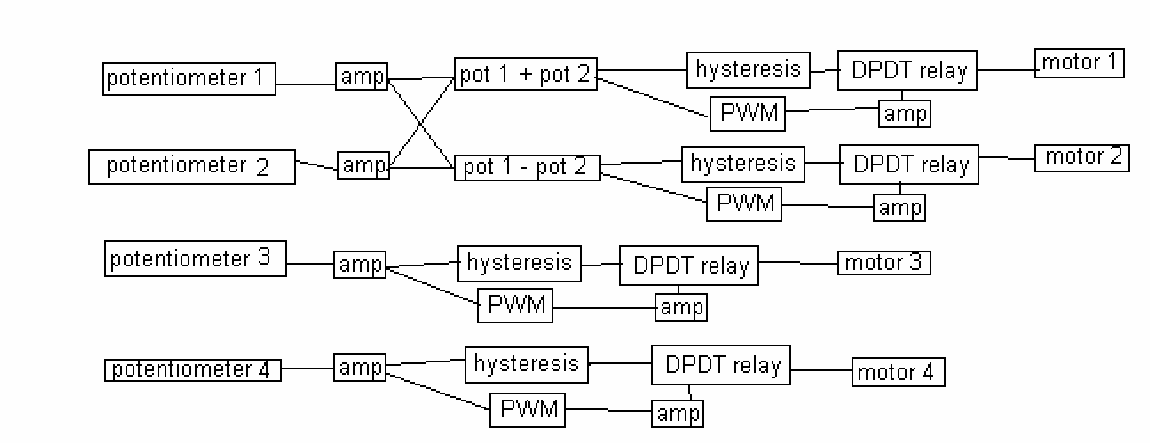
Appendix 1 ROV expenditures

Date	Location	Description	Cost ($)
1/21/2004	Radio Shack	components	-22.77
2/3/2004	Radio Shack	heatsink	-1.04
2/5/2004	hobbytron.com	robotic arm	-67.45
2/14/2004	ACE hardware	batteries and hardware	-9.26
2/23/2004	Radio Shack	components	-22.33
2/27/04	Falmouth Lumber	PVC	-17.01
2/27/2004	ACE hardware	L-bars and hardware	-83.60
2/28/2004	Radio Shack	switches	-21.47
3/14/2004	ACE hardware	hardware	-11.10
3/15/2004	Radio Shack	components	-9.21
3/17/2004	Radio Shack	switches	-12.25
3/18/2004	ACE hardware	hardware	-11.07
3/24/2004	Radio Shack	12V regulator	-1.56
3/25/2004	Radio Shack	components	-65.38
3/26/2004	ACE hardware	U-bolt	-0.93
3/26/2004	West Marine	caulk	-10.49
3/26/2004	Radio Shack	components	-4.70
3/27/2004	Radio Shack	components	-4.17
3/27/2004	Radio Shack	project boxes	-7.96
3/28/2004	Johnson Electric	16 gauge wire	-23.00
3/30/2004	Radio Shack	banana plugs	-22.41
3/31/2004	Radio Shack	project boxes	-10.48
4/3/2004	Radio Shack	banana plugs	-35.09
4/3/2004	West Marine	bilge pumps	-75.05
4/3/2004	ACE hardware	hardware	-1.85
4/10/2004	ACE hardware	hose clamps	-15.40
4/14/2004	Radio Shack	power supply	-104.99
4/14/2004	ACE hardware	hardware	-8.40
4/20/2004	Radio Shack	plugs + switches	-31.44
4/20/2004	ACE hardware	hardware	-2.51
4/21/2004	Radio Shack	banana plugs	-41.38
4/21/2004	Radio Shack	banana plugs	-8.38
4/21/2004	WHOI stockroom	O-ring grease and hardware	-34.26
5/1/2004	WalMart	baskets	-12.52
5/1/2004	Radio Shack	components	-39.81
5/5/2004	ACE hardware	sponge	-4.08
5/5/2004	Radio Shack	Video tape	-12.06
5/6/2004	Radio Shack	cables	-6.91
5/7/2004	West Marine	hardware	-9.73
5/18/2004	ACE hardware	pvc	-11.26
	Cheaptickets.com	Tickets to California	-1700.00
	Woods Hole	parking	-10
	Falmouth Lumber	pvc	-17.01
	Berg Industries	Couplings and seals	-300.00
	Waldes Company	clip rings	-10.00
	WHOI stockroom	o-rings	-5.00
late Feb.	tower hobbies	propellers	-26.89
Jan	WHOI OSL lab	camera- donation	(100.00)

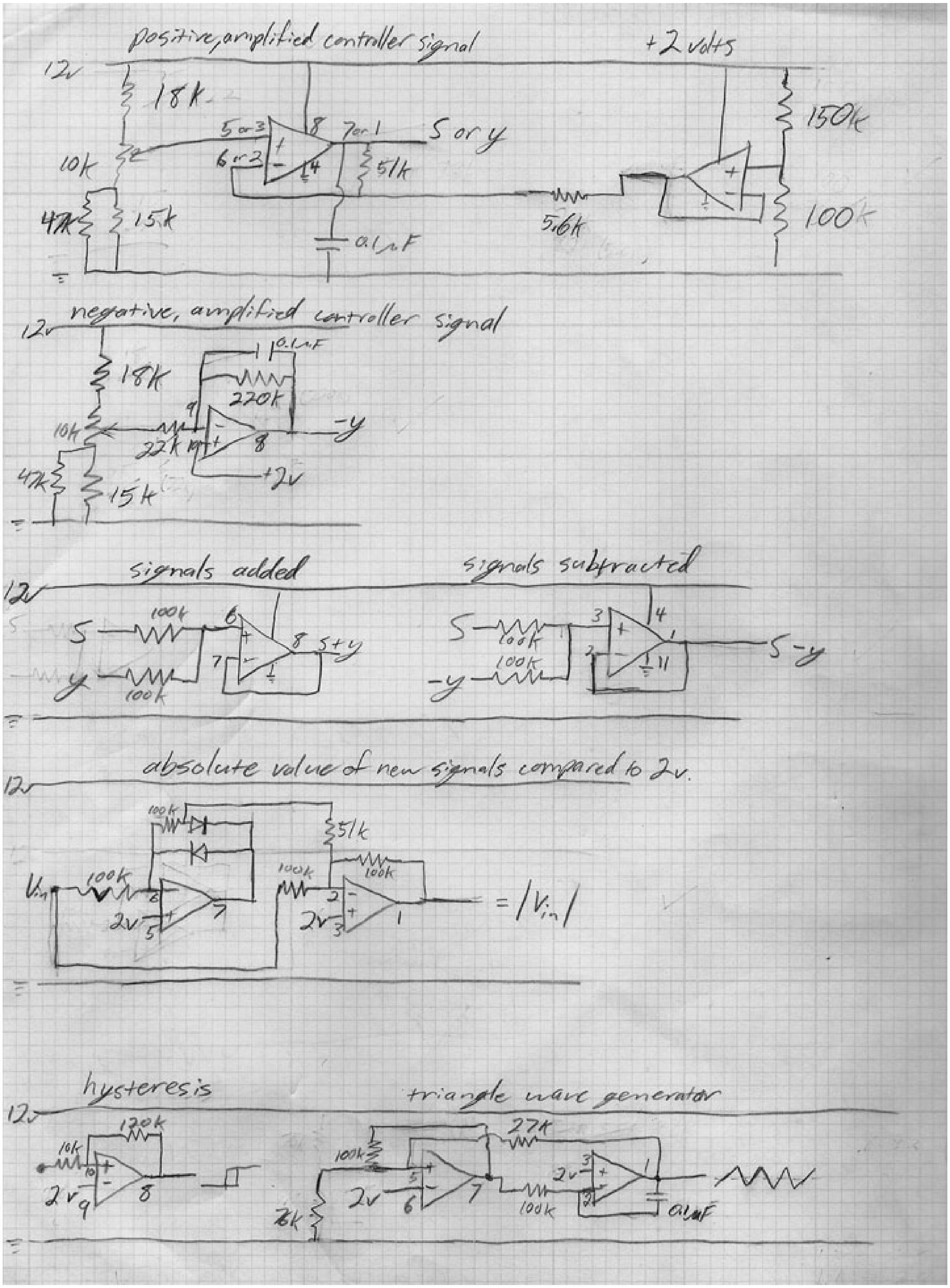
Jan	WHOI OSL lab	brushed DC motors (from scrap)- donation	(100.00)
3/25/2004	Falmouth Academy	check	100.00
	Sippican	check	500.00
	Hydroid	check	500.00
	Webb Research	check	500.00
	MATE	check	100.00
	Regionals 2nd place prize	check	75.00
	MATE	check	1500.00
			311.34



Appendix 2: Electrical Systems Schematic



Appendix 3: Circuit Diagram



Appendix 4: Electrical Schematic

Propeller Testing 1/21/04 and 1/22/04

Prop description Motor winding number 885

# blades	color	radius (m)	pitch (cm/rev)	voltage	amperage	force (lbs)
2	grey	0.15	20	10.0	4.0	4.5
2	grey	0.1	20	12.0	3.6	5.0

Table 1: Propeller Testing data for propellers used

Power Budget **12V and 25A** **Total available power = 300 watts**

		quantity	Voltage (V)	Amperage per unit (A)	total Amperage (A)	Wattage per unit (watts)	total Wattage (watts)	% of available wattage
thrusters	4 in. radius prop	3	12	5	15	60	180	60
	6 in. radius prop	1	12	6	6	72	72	24
camera		1	12	0.11	0.11	1.32	1.32	0.44
camera motor		1	12	0.2	0.2	2.4	2.4	0.8
arm motors		2	12	0.2	0.4	2.4	4.8	1.6
control circuits		1	12	0.1	0.1	1.2	1.2	0.4
					21.81		**261.72**	**87.24**

Table 2: Power distribution

Estimated Motor performance

	current	voltage	wattage	force (lbs)	RPM	output torque	horsepower
4 in prop	3.6	12	43.2	5	645	345	0.0573
6 in prop	4	10	40	4.5	580	390	0.0531

Table 3: Motor performances, based on propeller

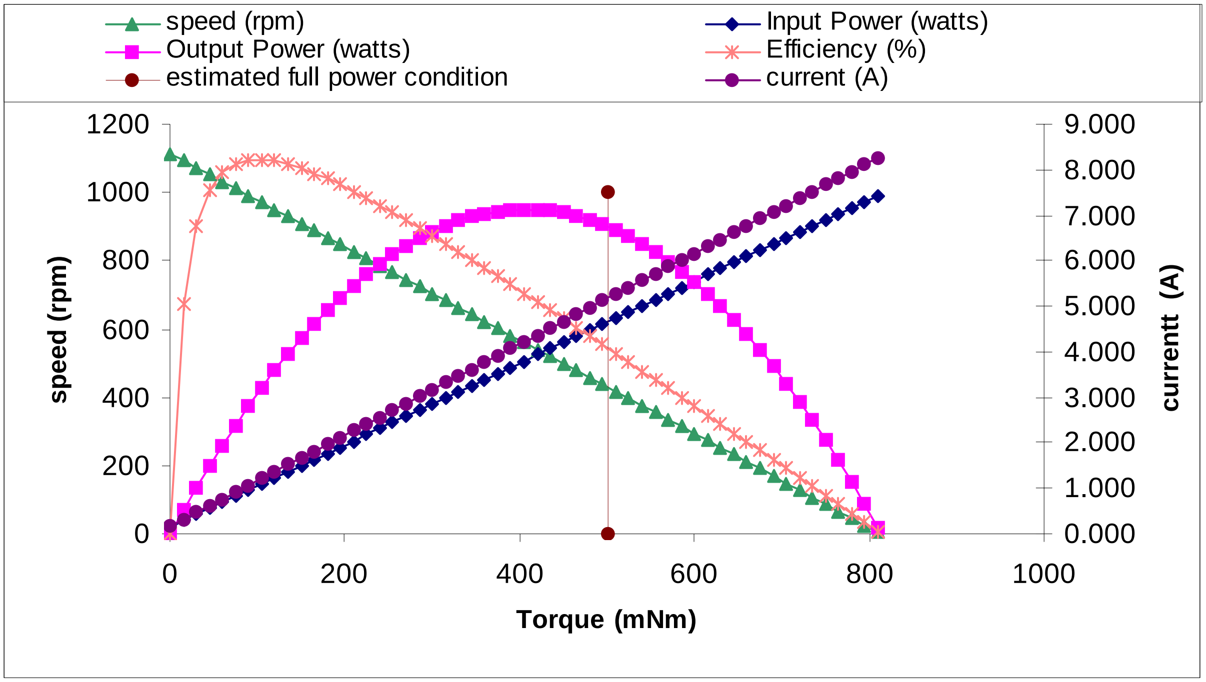


Figure 1: Motor Performance Parameters