The underwater Remotely Operated Vehicle

Swarthmore College Engineering Department

ENGR 90 – Senior Design Project

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Contents

Abstract

This project is an update of the 2006 underwater Remotely Operated Vehicle designed and built by Tyler Strombom and Alexey Rostapshov. They left a PVC frame with its attendant motors, battery compartments, and control systems. The project was intended to finish the 2006 uROV, while simultaneously upgrading and simplifying its electronic capabilities and water-proofing. The major upgrades included redesigning the H-Bridges used in the 2006 design to eliminate motor backspin and conceiving a mechanical seal for the water-proofing. The uROV is currently run via wired communications, but can be easily upgraded back to wireless communications via an XBee unit. The project cost ~$150 and was supervised by Professor Carr Everbach.

1 Introduction

1.1 General Submersible Information

The underwater Remotely Operated Vehicle (or uROV) is distinguished by the fact that it receives commands from a human controller operating at a remove in a comfortable environment but is independently driven via onboard propulsion systems. Generally, a tether is used to send both power and command and control signals to the uROV. This is specifically distinguished from an Autonomous Underwater Vehicle (AUV) which contains its own onboard power supply, is pre-progammed, and therefore does not receive commands from a human controller during operation. Essentially AUVs are given executable programs and left the alone. The lack of a tether increases flexibility of deployment, but at the cost of reduced ease of use and control. Generally, AUVs are used for initial exploration of an area in order to pinpoint optimal locations for follow-up uROV deployments. Currently uROVs are used in a wide variety of applications including undersea mining and drilling, construction, hull inspection and repair, and exploration, of which HydroProducts' RCV-225 and the RCV-150 designed for off-shore oil drilling are two early models [1].

1.2 A Brief History of uROVs

1864 Giovanni Luppis and Robert Whitehead of Luppis-Whitehead Automobile in Austria design a Programmed Underwater Vehicle (PUV) which carries explosives to an enemy boat. The torpedo is powered by compressed air and steered by a cord from the attacking ship.

1953 The first tethered exploratory uROV, "POODLE," is developed by Dimitri Rebikoff for underwater photography.

1962 The culmination of United States Navy experimentation and advancement results in the first wide-scale public exposure to uROVs. CURV (Cable Controlled Underwater Recovery Vehicle) recovers an H-bomb that had been lost in the ocean near Palomares, Spain after a U.S. B-52 bomber crashed into a KC-135 refueling plane [2].

1973 CURV rescues the crew of the wrecked submersible Pisces off the coast of Cork, Ireland with only minutes of air remaining in the submersible [1].

1.3 The Swarthmore uROV

2005 The Swarthmore uROV project was started in 2005 by Samantha Brody and Maila Sepri, who built a small (~ 1 ft^3) submersible which was fully controlled and powered pool-side via a tether. The robot was based on the Seafox deign by Harry Bohm [3]. The robot also had a camera mounted in a watertight container to enable pictures to be taken during dives. This project had several disadvantages, however, including the inflexiblilty in deployment necessitated by the bulky tether and the consequent reduction in freedom of movement. Other matters of concern included the flimsy nature of the frame, which tended to fall apart, and the low total thrust provided by the motors, which, when combined with the inability to control motor speed and the drag of the tether, led to suboptimal motion performance of the uROV.

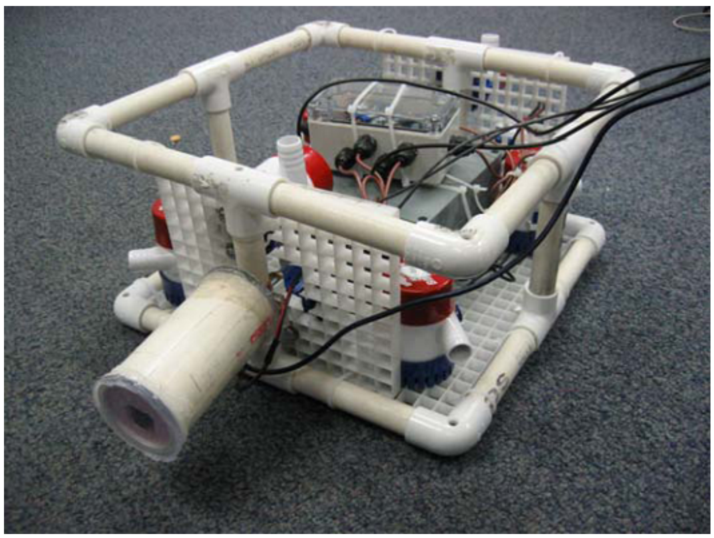

Figure 1: The 2005 uROV

2006 Thus, the following year the uROV was cannabalized in order to build a larger, more robust submersible. Alums Alexey Rostapshov (who worked on the 2005 uROV) and Tyler Strombom '06 built and tested the current uROV. The primary upgrades involved producing a system to vary motor speed and providing for onboard power. The electronics were designed as modular components in order to facilitate upgrades to the various subsystems. The new robot was fitted inside a PVC frame and consisted of 3 PVC tubes (for batteries and electronics) and 8 bilge pumps controlled by modified H-bridges. Numerous sensors were added to detect robot motion and leaks, while control was provided via a wireless transmitter. However, during the testing process, an unforeseen problem with the circuit boards, most likely resulting from problems during installation, resulted in the robot failing before it could be tested in the Ware Pool.

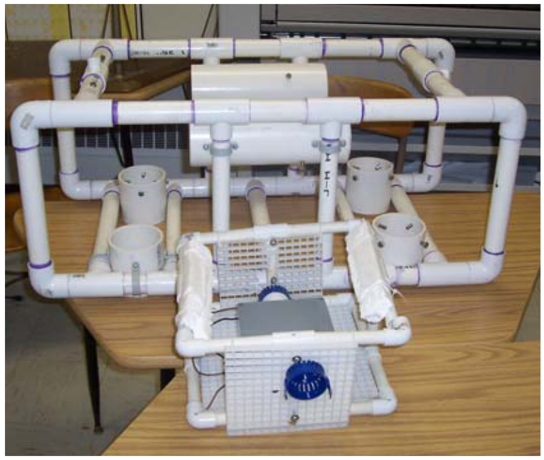

Figure 2: 2006 uROV (background) and 2005 uROV (foreground)

2008 The current project was an upgrade of the already existing system in an attempt to make the uROV sea-worthy. The main problems noted by the 2006 team involved the need for a bigger electronics compartment and feedback from the H-bridges causing a cascading failure of the entire control module. The overarching goal of the 2008 E-90 Project was to reduce the complexity of the system in order to facilitate ease of use and increase robustness.

To accomplish these goals, several modifications were made to the existing submersible. The waterproofing system was completely reengineered, the control boards were redesigned to allow more control and add increased redundancy, and the wireless system was removed to increase reliability of communications. As such, the current iteration of the Swarthmore uROV can be considered as a hybrid uROV-AUV, wherein power is supplied onboard, but control is provided remotely via wires.

2 Mechanical Systems

2.1 Frame

The 2006 uROV frame (with the 2008 fittings) can be seen below. It has a rigid frame made out of 1" and 1.25" diameter PVC piping. Two valve fittings were installed on the top to enable flooding of the frame, allowing the buoyancy of the uROV to be adjusted mechanically. It is important to note that, if the frame is flooded, it must be flooded fully. Otherwise the water will shift inside the frame, causing the uROV to become unbalanced during movement in the water.

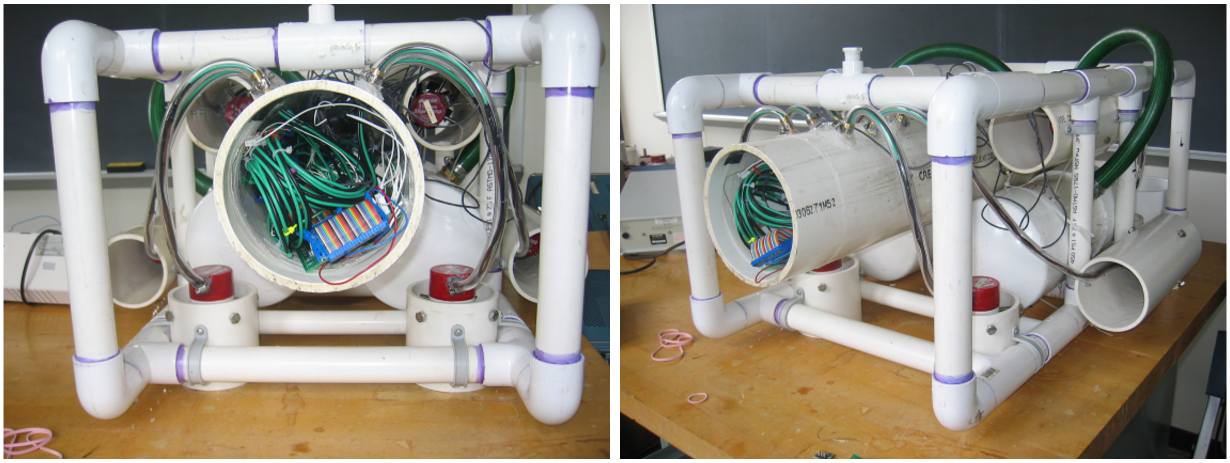

Figure 3: (a) Front and (b) Side Views of the 2008 uROV

2.2 Propulsion

The uROV is driven by 8 modified Rule 1100 GPH bilge pumps (4 vertical and 4 horizontal). These were upgraded from the Rule 550 GPH bilge pumps used by the 2005 uROV. The casings for the bilge pumps were cut away and the original bilge fans were replaced with Masscool DC 12V, ball bearing computer cooling fans to increase surface area and therefore thrust. This is different from the 2005 uROV, in which thrust was provided unidirectionally from the output of the bilge pumps.

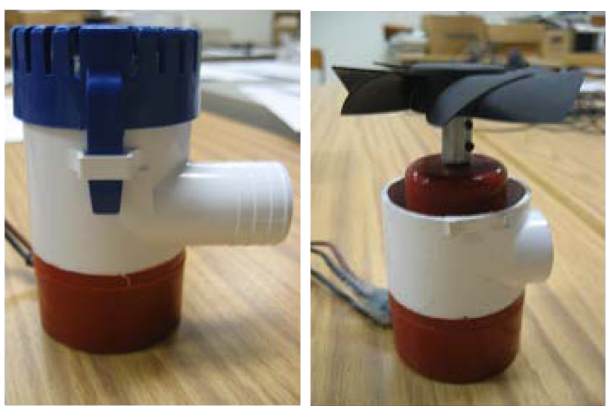

Figure 4: (a) Bilge Pump and (b) Motor (Modified Bilge Pump)

Because the bilge pumps can be run in reverse and propulsion is provided by the fan blades, the geometry of the motors allows the uROV to rotate about its own axis in all three directions, as well as preform non-holonomic movements.

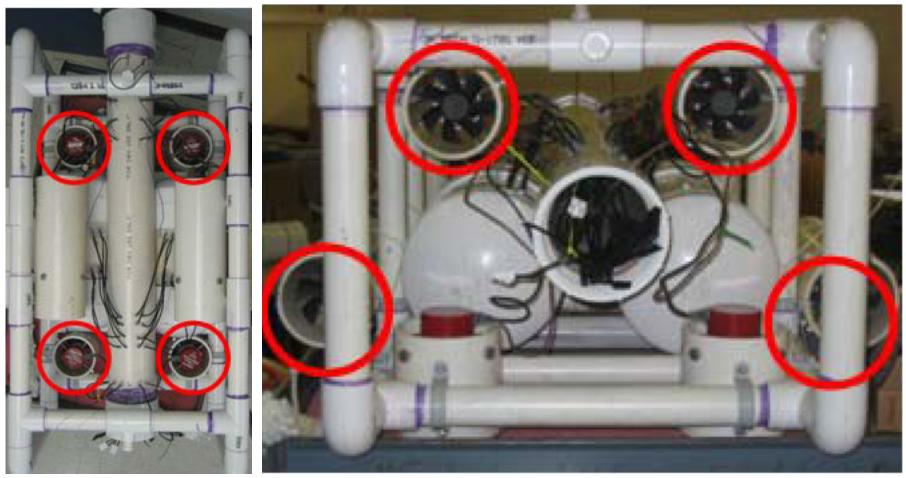

Figure 5: (a) Vertically and (b) Horizontally Mounted Bilge Pumps

2.3 Watertight Compartments

Two battery compartments made out of 6" diameter PVC held a total of four 12V batteries to power the submersible. Additionally, in the original uROV, the electronics compartment was made out of 4" diameter PVC. However, the small interior lead to wires being pulled out during installation of the PCBs, and most likely lead to the short that caused the uROV to fail and emit black smoke in 2006. The compartment has since been upgraded to 6" PVC, despite the negative side effects of the increase in buoyancy. Originally, a piece of 5" diameter PVC pipe was drilled for this purpose. However, it was impossible to obtain the necessary fittings for the 5" PVC, thereby necessitating the upgrade to 6" PVC. The additional internal volume is a concern as the original uROV (with the 4" diameter electronics compartment) was neutrally buoyant. Therefore the addition of the larger compartment with only negligible additions in weight (from the new waterproofing system, described in Section 2.4 below) means that the uROV will have substantial positive buoyancy, which will need to be counteracted with either flooding the frame or adding weights. The PVC compartments were placed in a catamaran shape, in which the battery compartments served as the outriggers to the higher placed electronics compartment

Initially, the 4" diameter PVC had a transparent faceplate to facilitate the use of a camera, which was intended to communicate to the computer over a dedicated channel. However, time constraints necessitated that a second end cap could not be manufactured this semester. Also, because it was necessary to be able to access the compartments between runs in the water, both ends of the PVC could not be sealed. Instead for each compartment, one end cap was glued on with PVC cement while the other end cap was fitted on with vacuum grease and sealed with RTV sealant.

2.4 Waterproofing

The original uROV routed the wires from the battery compartment to the electronics compartment and from there to the motors by feeding the wires through holes drilled in the PVC and sealed with standard RTV sealant. This meant that each battery compartment fed 8 wires for power and one for the leak detection, while the electrical compartment had an additional 2 wires per motor and a final wire for the wireless buoy for a total of 35 wires. While this design never failed, it was decided that one important step for the upgrade of the uROV would have to include a better, preferably mechanical, system for maintaining hull integrity under water. Initially, water-tight connectors sold by many distributers in the marine industry were considered. However, the cost for a sufficient number of connectors able to take 12V/6A and be easily connected/disconected was prohibitive: about $50 per connector.

Instead, after an iteration of ideas, it was decided that the wires should be run through hosing which in turn would be fixed to the PVC with hose barbs. This would help prevent the wires from being pulled out and flooding the compartments, as well as reducing the total number of holes that needed to be drilled into the PVC. Teflon tape was used to ensure that the hose barbs would not leak. Two pairs of 1" hose barbs were used to shepherd the wires from the battery compartments into the electronics compartment. An oversized heavy duty garden hose was cut up to provide the sheathing for those wires. The wires to the motors were fed into 1/4" hose barbs and through 1/4" clear flexible tubing. This tubing had the disadvantage that at high pressures it would tend to collapse, increasing the pressure in the compartments and possibly causing leaks and popping the end caps off. This concern was alleviated by putting a vacuum on the compartments, partially compressing the tubes prior to submersion, and ensuring that substantial additional compression would be necessary to expand the end caps.

The layout of the bilge pumps put a maximum size on the tubing inner diameter for the wires going to the motors. Because the wires entered the bilge pumps through a rubber nipple, the tubing had to fit snugly over the nipple to ensure water-tightness. 1/4" tubing was found to fit these specifications, and eight 1/4" hose barbs were procured for the electronics housing. All of the hosing was secured to the barbs and bilge nipples with hose clamps as an additional precaution and to reduce the worry of the system being pulled apart. Finally, every joint was caulked with RTV sealant as one final safeguard.

This design had one additional benefit with a concurrent dis-benefit. In 2006, it was discovered that the end caps held on by vacuum grease had a tendency to slide and leak during de-pressurization (or, presumably, surfacing as this was only tested in a pressure chamber). To counter-act this tendency, a valve was installed on the compartments to allow

Figure 6: Waterproofing System for the uROV: (a) Battery to Electronics Compartment and (b) Electronics Compartment to Motors

them to be put under a slight vacuum. Because the compartments are all connected, they can be vacuumed simultaneously with only one valve (decreasing the possibility of a leak at each extra valve). This vacuuming would also reduce pressure in the hoses, causing them to collapse before immersion. The concern otherwise was that the collapse of the hosing under pressure would be sufficient to loosen the vacuum greased end caps during the uROV's descent in the water.

The opposing concern was that if a leak did develop, it would not be contained. While it was decided that the benefits outweighed the cost for the three main compartments, it is a serious issue that should be addressed in future iterations of the project. To partially alleviate this problem, the hosing was filled with RTV sealant near the bilge pumps to prevent a leak at that point from flooding the entire vehicle. Additionally, the hoses all enter the compartments from the top in order to increase the time between the flooding of the initially flooded compartment and the other compartments. To this end, the hose fittings should be sealed internally to prevent or at least reduce exchange of water between the compartments.

3 Electronic Systems

3.1 Overview

Because of the complexity of the PCB for the uROV was designed to be modular in nature. This allowed various subsystems to be replaced without necessitating the replacement of the entire electronics system. The general structure of the PCB is shown below. This also enabled us to reuse many of the boards from the 2006 uROV while still updating the boards where necessary.

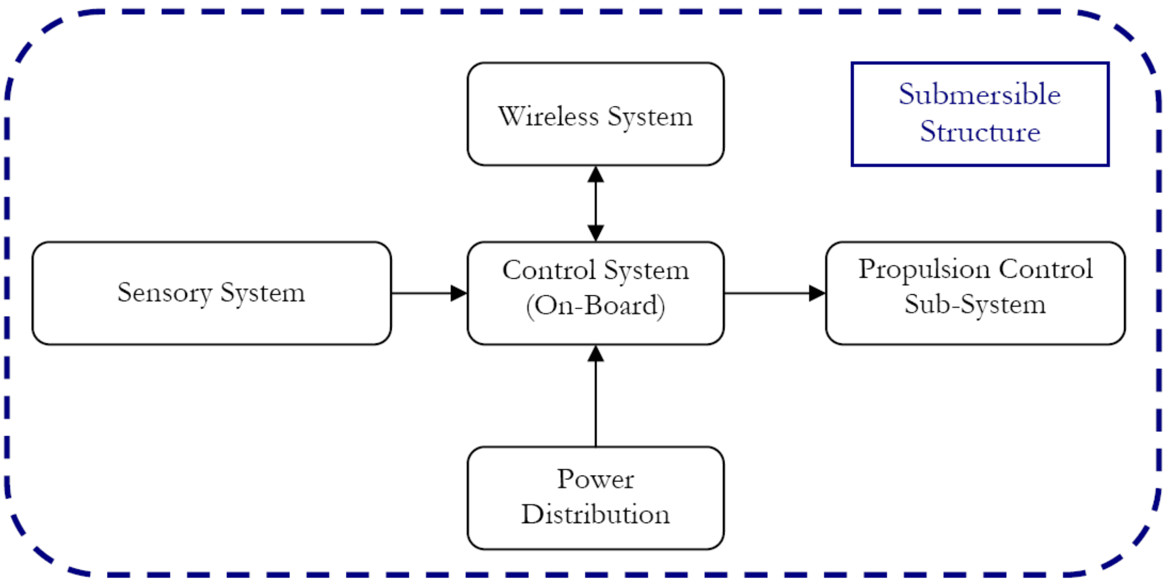

Figure 7: Modular Design Concept for the uROV

The electronics system on the uROV was the cause of failure for the 2006 group. Whether the problem was bad wiring or short circuits caused by the need to run wires through the cramped compartment was not possible to verify due to the extensive damage of both the fire and the process of removing the sensor boards from the electronics compartment.

However, it was clear from inspection of the electronics at the beginning of this year that both could have caused problems. During disassembly of the electronics compartment (the original compartment had been left intact with no effort made to determine to cause of the short or fix it), it was noted that several of the power cables had been pulled out. Additionally, numerous hexfets in the H-bridge board had been broken or crisped. Initially, all of the obviously broken hexfets were replaced and the H-bridges were tested in isolation. However, it quickly became apparent that many more of the hexfets were fried, and that a new board would have to be assembled. Before that process began, however, it was decided to overhaul the design of the H-bridges (see Section 3.2.3).

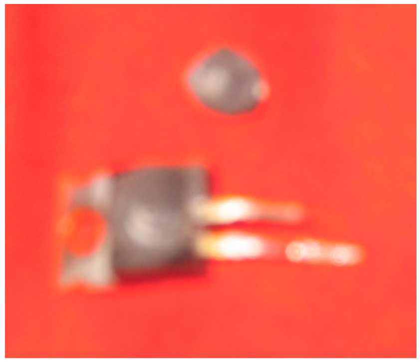

Figure 8: A Burnt-out Hexfet Found in a 2006 H-Bridge

3.2 Control Support Systems — Printed Circuit Boards (PCBs)

3.2.1 Power PCB

The rail and ground of all four batteries are fed in parallel to a single Power PCB module, and then distributed to the eight motors. The original design uses two pairs of wires per battery to carry the current load. This system was not upgraded, as it was not necessary would have required rebuilding the Power PCB and replacing the Tamura hall-effect sensors. A 16-wire ribbon cable connected the hall-effect sensors on the Power PCB to the sensor board in order to allow the current flow to each motor to be monitored and adjusted individually. The Power PCB was put in backwards at the the last minute in order to facilitate access to the power input wires, putting a kink in the ribbon cable and reversing the hall-effect sensor outputs (sensor 8 goes to motor 1, sensor 7 to motor 2, etc).

Figure 9: Power PCB

3.2.2 Power

High-Voltage Batteries Power for propulsion was supplied by four 12V, 12 Amp-Hour Sealed-Lead-Acid (SLA) Batteries. Two batteries were placed in each battery compartment providing up to 48 Amp-Hours of power. Power was supplied via two pairs of 16 gauge wire per battery.

Low-Voltage Batteries The control system is powered by a two cell 7.4 volt 910 mAh CellPro Lithium-Polymer (LiPo) battery. It is separate from the propulsion system in order to maintain the robustness of the system and to protect the OOPic and sensor board from a power back-surge. The wireless transceiver was also powered by a separate LiPo battery. Both batteries were charged using a Graupner LiPo Charger 4 with a jury-rigged connector.

3.2.3 Control Boards

In order to control the speed of the motors, Alexey Rostopshov and Tyler Strombom used H-bridges. The most basic version of an H-bridge consists of two pairs of one N– and P– Channel metal–oxide–semiconductor field-effect transistors (MOSFETs) each. They are placed in a configuration that resembles and H (hence the name). The N-Channel transistors are placed at the ground with the P-Channel transistors placed in series like two vertical lines. Between the N– and P– Channel transistors, a motor is linked across the two circuits to complete the H. Each of the pairs can be independently turned on and off. When both are on or off simultaneously, no current can flow through the motor. However when one is on and the other off, current can flow. Switching which pairs are on and off reverses the current, driving the motor backwards.

Because the H-bridge acts as a gate, a pulse width modulated (PWM) signal can be used to control the speed of the motor by opening the gate for a percentage of a given duty cycle while the other gate remains high or low. Currently, the oPWML object in the OOPic is used to control the H-bridges, which uses a duty cycle of 1 second.

Initially, the H-bridges had 3 inputs: PWM, PWM_Inv, and Active. A diagram of the H-bridges is shown below. Dual pairs of N– and P– Channel hexfets were used to direct the current, while a third N-Channel hexfet was used as an on/off switch. This configuration had several advantages. It allowed for a separate channel to active the H-bridge. Without the activation, any PWM signals would not turn the motors on. After activation, the PWM signals could adjust the speed of the motors via an increase or decrease in their duty cycles. Furthermore, when the Active Channel was on, the H-bridges were always on. Therefore, if the gate transistor could not be turned off, power would always flow.

Unfortunately, further analysis showed that the OOPic being used to control the uROV did not have a sufficient number of channels. Instead of having 3 inputs per motor, it had space for only 2. Therefore, to create the PWM and PWM_Inv signals, a single PWM signal was split: one running through a standard 7407 open collector buffer, the other through a 7406 inverting buffer. The Active signal was sent through a second 7407 buffer.

The outputted signals were sent to their respective inputs on the H-bridge. The result was that when the PWM input had a low duty cycle, the motors would turn clockwise and

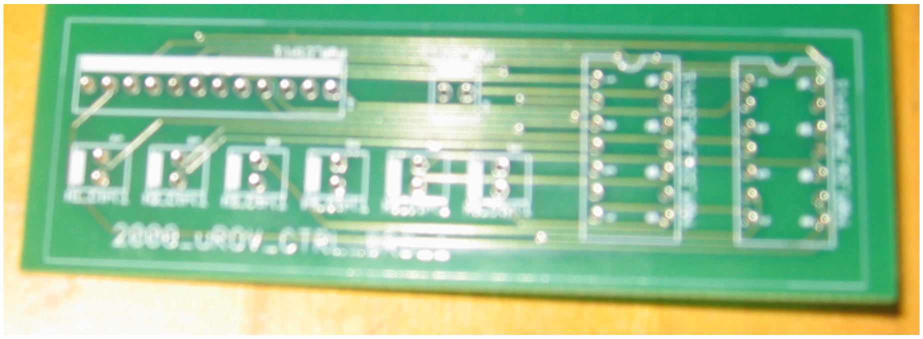

Figure 10: Control Board

when it had a high duty cycle they would turn counter-clockwise. At an equal duty cycle (time$_{on}$ = time$_{off}$), the motor would twitch back and forth. This problem was not noticeable when originally implemented because the frequency of the PWM cycle was high enough so as to not allow the fan blades to actually begin spinning one direction before being given current to spin in the other direction. Thus, putting any voltage across the Active pin would cause current to flow and the motor to spin regardless of the input of the PWM signal. This also greatly reduced the breadth of motor speeds, as effectively only every other speed could be reached.

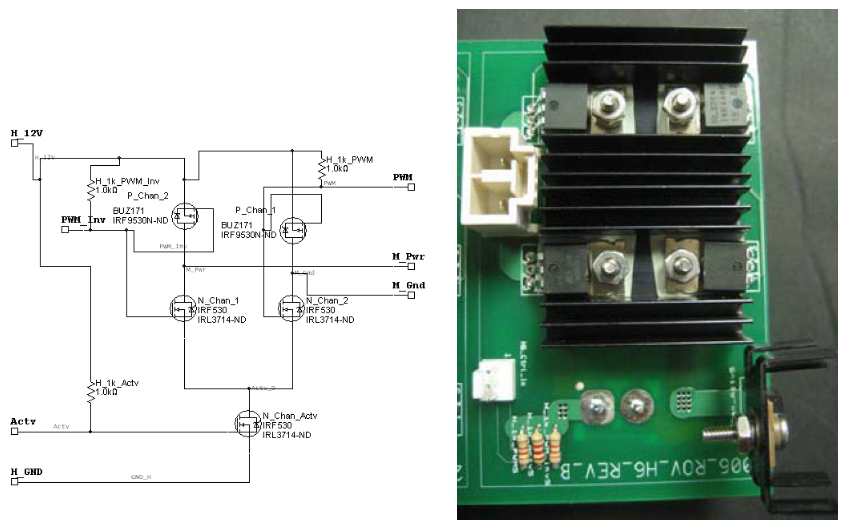

Figure 11: 2006 H-Bridge (a) Schematic and (b) PCB Board

It was therefore decided to re-design the H-bridges. At first the idea was to change the two inputs from PWM and Active to PWM clockwise and PWM counterclockwise while using a final pair of open channels to act as a pair of “meta-switches,” turning on sets of H-bridges (one for the horizontal motors, the other for the vertical motors). However, it turned out that the documentation used to determine that there were 2 free channels was outdated: the channels were being used by the wireless. After scrapping that idea, another series of plans were considered until finally it was decided to implement simple H-bridges without the activation channels. However, an additional concern was raised. While buffers were needed to protect the sensor board and OOPic from feedback, the current setup was non-optimal, as it resulted in a constant current bleed from the 12V source being used to buffer the 7407 open collector outputs. Therefore, resistors of 12 kΩ resistance were used to reduce the current trickle. This was possible because the duty cycle used by the OOPic has a low frequency, giving enough time to buffer the 5V input during the cycles. This resulted in the simple H-bridge, shown below. Three 13" x 3.75" H-bridge boards were designed in Ultiboard Version 8 and built by Advanced Circuits. The third board was purchased as part of a package in case the first two were damaged irreparably and was only used for prototyping. Unfortunately, the Ultiboard (Version 7 Education Network) blueprints used by Alexey Rostapshov were not easily modifiable. An initial attempt to re-design the H-bridges had to be discarded, and eventually the each of the four H-bridges in the board had to be built separately piece by piece. This configuration has the added advantage that if one of the channels is stuck either closed or open, the other channel can be brought to its level in order to shut off the circuit.

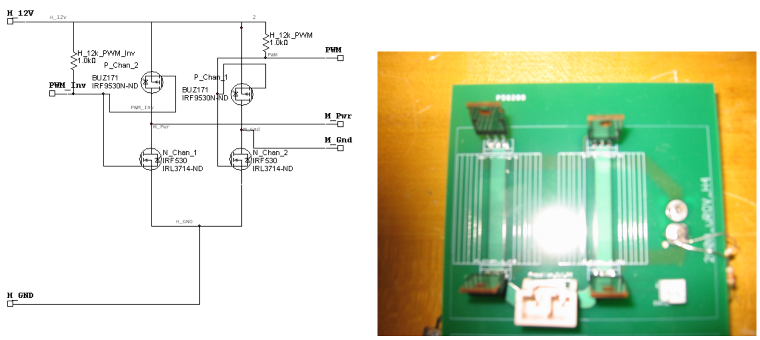

Figure 12: 2008 H-Bridge (a) Schematic and (b) PCB Board

3.3 Sensor Sub-System

The sensor system built by Alexey Rostapshov and Tyler Strombom was left intact during the upgrade. However, a brief overview is necessary. The general framework of the system is shown below..

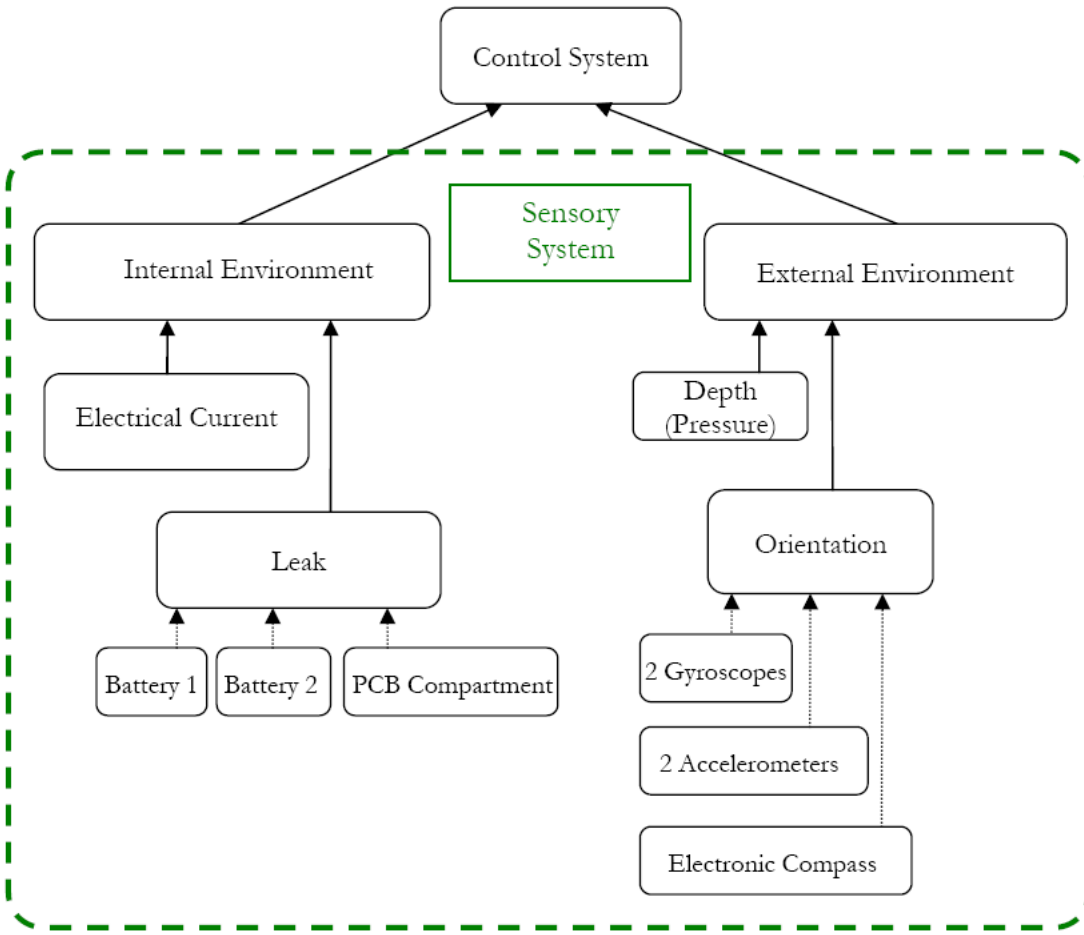

Figure 13: Sensor Sub-System

The current uROV has a variety of sensors, which Alexey Rostopshov and Tyler Strombom divided into two groups: external (position) sensors and internal (damage control) sensors. The former serve to locate the current position and movement of the uROV and are measured by four components: accelerometers, gyroscopes, compass, and depth sensor. Because of the nature of the sensors, the operating environment, and the desire to be able to operate the device far away from the operator's position, a number of redundancies were built into the system. This includes the ability of the gyroscopes to act as inertial compasses and the accelerometers to check the gyroscopes measurements for pitch and roll. The internal sensors include current sensors for the motors and the leak detection system. Additionally, because the number of sensor inputs exceeded the capacity of the PIC, it was necessary to use a pair of 8–to–1 Analog Devices' model ADG608 multiplexers to reduce the number of inputs per iteration to the PIC. All of the sensors and motors are routed to the pic via the sensor board, which is shown below.

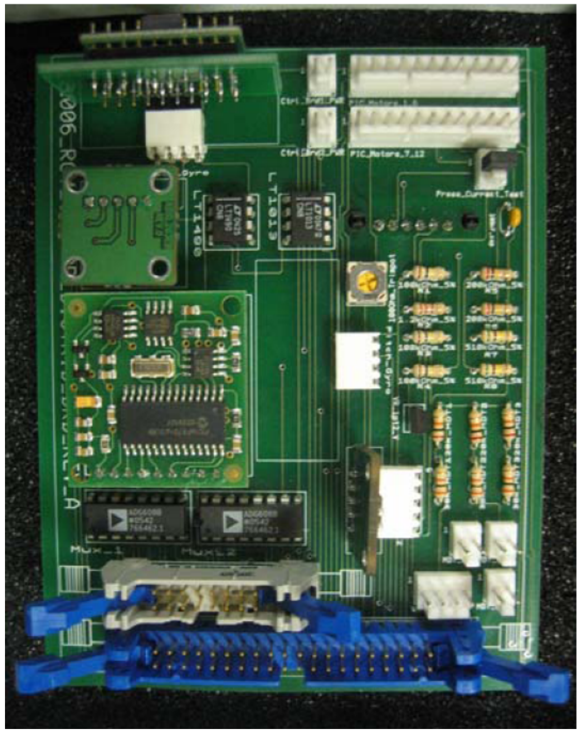

Figure 14: Sensors Board

3.3.1 Accelerometers

Two Analog Devices ADXL203 iMems dual-axis accelerometers were mounted perpendicular to one another. They are capable of measuring accelerations from as little as 1mg to 1.7g. They are mounted in the xy– and xz– planes to measure pitch and roll after accounting for the effects of gravity. These, combined with the pressure sensor and the back-up gyroscope should be sufficient to fully locate the uROV in the water.

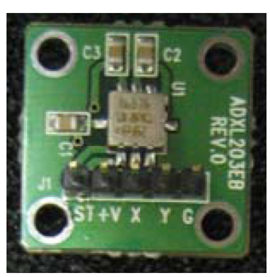

Figure 15: Analog Devices ADXL203 iMems Dual-Axix Accelerometer

3.3.2 Gyroscopes

Analog Devices ADSRS401 iMems gyroscopes were used to determine the pitch and roll of the uROV. These sensors output a baseline of 2.5 volts, with deviations from this value corresponding to the linear rotation speed of the uROV. Thye are sensitive enough to read rotations of up to 75°/sec. This system is designed to keep the robot oriented vertically, so that the relative positions of all its components to the surroundings are known and so that any propulsion results in movement in the proper direction. These are intended to augment the magnetic compass readings. Finally, both gyroscopes has an intrinsic temperature sensor for calibration, which will be used to detect overheating.

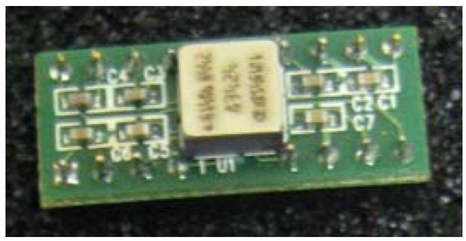

Figure 16: Analog Devices ADRS401 iMems Gyroscope

3.3.3 Electric Compass

Primary navigation was intended to be performed by a Devantech CMPS03 magnetic compass module that uses a pair of magnetic field sensors mounted at right angles to compute the direction of Earth's magnetic field. This system should orient the uROV in the horizontal plane. However, an unseen problem with this compass occurred when it was removed from level. As declinations of as little as 10 °, it would read as much as 15° off of its true orientation. Therefore, the gyroscopes are needed to help maintain the uROV on an even keel.

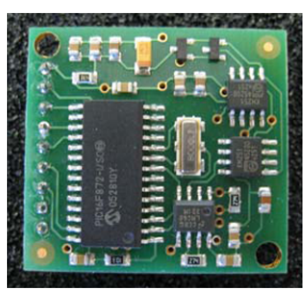

Figure 17: Devantech CMPS03 Magnetic Compass

3.3.4 Depth Sensors

Given the susceptibility of the uROV to leaks, a pressure transducer was used, specifically a MSI Sensors Model 85 Ultrastable pressure sensor. It is the only "external" sensor to be located physically external to the uROV: it is screwed into a tap on the bottom of the electronics compartment. The water pressure on the side of the uROV can be translated into depth readings. It can measure pressures from 0 – 30 psi, giving a maximum depth of approximately 20m, allowing the uROV to be kept above its designed floor.

Figure 18: MSI Sensors Model 85 Ultrastable Pressure Sensor

3.3.5 Leak Detection Sensors

Because of the extreme delicacy of the electronic components of the uROV, leaks are of a major concern. Therefore, a number of pieces of Norscan Industries Moisture Detecting Tape (MDT) are also mounted on the uROV, consisting of two parallel copper wires embedded in a nonconductive cloth matrix, and connected by a voltage source. A leak will short-circuit the lines, giving warning when a compartment begins to flood. Each compartment is run on a separate leak detection system so that leaks can be pinpointed.

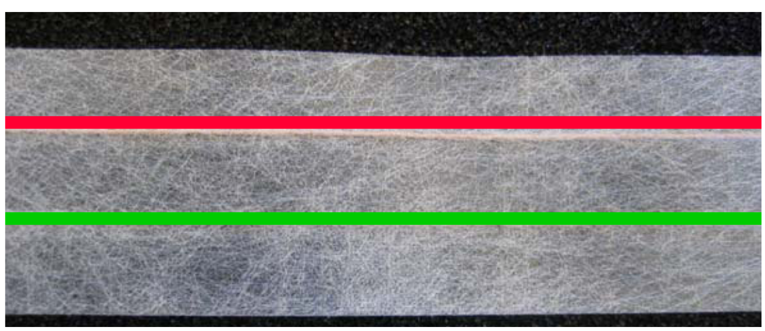

Figure 19: Norscan Industries Moisture Detecting Tape

3.3.6 Current Sensors

Because of the possibly high current draw of the motor subsystem, it was necessary to implement a means to monitor the power drawn by each motor in order to prevent damage to the electrical system. Tamura Corporation model L07P015S05 hall-effect sensors were used. Each sensor can measure up to 15 amps on two distinct traces. Therefore, each sensor was put in series with a pair of H-bridges, and their outputs were sent to the sensor board.

Figure 20: Tamura Corporation Model L07P015S05 Hall-Effect Sensor

3.4 Communications

The 2006 uROV was initially configured for wireless communication. However, because of the inability of the transmitter to communicate through water, they found it necessary to place the wireless transmitter in a buoy tethered to the uROV. However, implementation of the wireless transmitter was fraught, as the receiver was specially designed by another group in 2006, and has since disappeared. Rather than redesigning the transmitter, a decision was made to control the uROV with a wire. This was further supported by the cumbersome nature of the buoy itself: running the communications wire all the way to the computer adds very little drag and few limits on the motion of the robot in comparison with the buoy. Eventually, it is expected that the submersible will be upgraded back to wireless control; however, the current goals do not require the implementation of wireless control and the upgrade should attempt to use a transmitter that works through the water, as the current designed operating depth is only 12ft.

3.5 On-Board Control System — OOPic

An onboard OOPic II+ microcontroller manufactured by Savage Innovations was used to control the uROV. The OOPic uses a convenient object-oriented programming interface capable of understanding Basic, C, and Java. Initial programming was done in Basic, and therefore subsequent programming has been done in the same language. To maintain the modular nature of the control system, the OOPic is connected to the rest of the system by a 40-pin ribbon cable, terminating on the sensor board. All signals and controls from the sensors, Power PCB, and H-Bridges are routed through the sensor board and thence to the OOPic. Unfortunately, initial design estimates for necessary processor capacity were too low, and the controller does not have sufficient RAM for processing multiple inputs or sufficient channels for outputting motor commands. The result is reduced flexibility, both in possible sensor upgrades and in movement planning as the OOPic can only control up to 8 independent motors in its current configuration. Furthermore, one of the I/O lines (I/O 24) was blown – either at the Pic or in the Sensor Board – after one of the H-bridges blew due to a faulty transistor. This necessitated slaving two of the motors together, further reducing the ability to finely adjust the movement of the ROV. Finally, during last minute implementation, the voltage regulator on the OOPic was fried. It was replaced, but there needs to be further diagnostics preformed on the Pic.

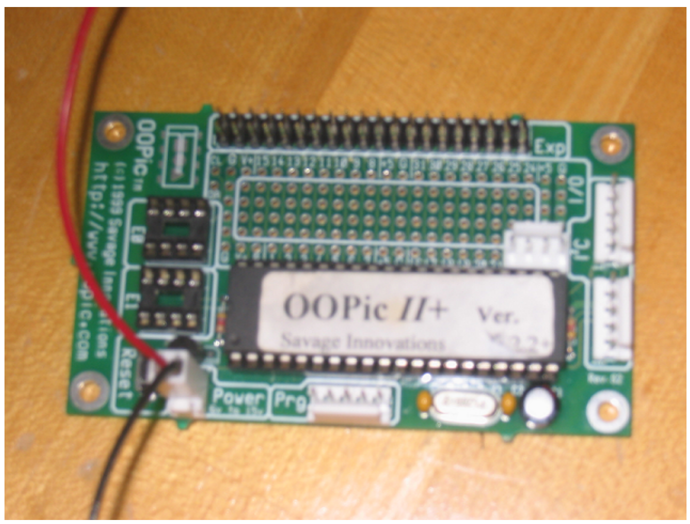

Figure 21: Savage Innovations Object Oriented Programmable Interface Controller (OOPic)

The problem of insufficient I/O lines can be resolved one of two ways: either replacing the OOPic with a more powerful PIC capable of managing the more numerous inputs and outputs, or adding a second OOPic in parallel using its built in Dynamic Data Exchange capacity to increase the processing capacity. While the ease of programming with the OOPic is appreciated, the first suggestion should most likely be preferred.

Communications with the OOPic were preformed via a USB–to–RS-232 converter manufactured by KeyAccess and an RS-232–to–TTL converter. Initially, we did not have any TTL level converters and it was necessary to manufacture one. The necessary schematics can be seen in Appendix A. Programming is done via the I/O lines 22 and 23 and can be plugged into either the sensor board or the 4-pin connector added to the OOPic in the prototyping area. The 5-pin programming connector is for parallel programming only.

4 Software

4.1 GUI

All of the original software including the graphical user interface (GUI) was written in Visual Basic 6.0. However, in the intervening years that program has been super-ceded by Visual Basic .NET, which is not 100% backwards compatible with VB 6.0. After several unsuccessful attempts to upgrade the software, it was decided to scrap the code and run the motors via simple commands to the OOPic as a proof of concept.

Eventually, it is hoped that a GUI will be written to control the uROV, and code added to control individual motors and motor speeds using the current data from the Hall Sensors. This would allow the controller to compensate for unequal motor outputs.

4.2 OOPic

The motors are controlled in three groups via the ooPic 6 Compiler: the four vertical propellers (for surfacing and sinking), the four horizontal propellers in the same direction (for forward motion), and the four horizontal propellers in opposite directions (for turning). This gives the ability to rise and sink, move forwards and backwards, and pivot right and left. The code is shown in Appendix E.

5 Disscusion

Currently, the only problem preventing the uROV from being placed in the water is the presence of one or more undiscovered leaks. Initial estimates regarding the watertightness of the hose barbs were overly optimistic. Additionally, several of the taps were make overly deep, increasing a the chance of a leak. Therefore, it is recommended that a new entire electronics compartment be tapped and the hose barbs be reinserted with additional teflon tape.

While the uROV could se several improvements in software and the inclusion of a more powerful Pic, the uROV is full operational from a electronics perspective. A computer can control the motors both individually and collectively (except for the two bow motors, which were slaved together).

Additional improvements suggested include adding a wireless transmitter that can transmit through the 12ft of water in the Ware Pool and a clear faceplate for the uROV so that a camera could be installed.

6 Conclusion

Despite the anticipation that the uROV would be operational for use in the pool at the end of the semester, many improvements were made. Most specifically, both the motor control circuits and the waterproofing were improved and simplified. Disassembling the uROV should now only require the removal of the hoses: the wires can be disconnected at either end and fed back through the hose barbs. The electronics suite is fully functional and can control every motor.

The final remaining hurdle to actual testing of the uROV in the pool is to detect the leaks in the hose barbs. Initially compressed air was run into the compartment, and a leak was found. However, subsequent depressurization showed that at least one more leak exists, and will need to be sealed.

Discounting the leaks, the uROV has be improved with a more robust design and is ready for its first test run in the pool.

7 Acknowledgements

The Swarthmore Engineering Department: For their general support and advice throughout the project.

Professor Carr Everbach: For his help and support throughout the project. Specifically, for helping teach Ultiboard, procure the new waterproof modules, and design the waterproofing system.

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Don Reynolds: For his help in preparing and tapping the PVC.

Doug Judy: For his help in gathering the necessary fittings for the PVC and assembling the uROV compartments.

Alexey Rostapshov: For visiting Swarthmore several times over the course of the semester in order to assist with reconstructing the original processes behind the 2006 uROV.

The Swarthmore Track & Field Team: For keeping me sane throughout the semester.

A RS232–to–TTL Converter

[5]

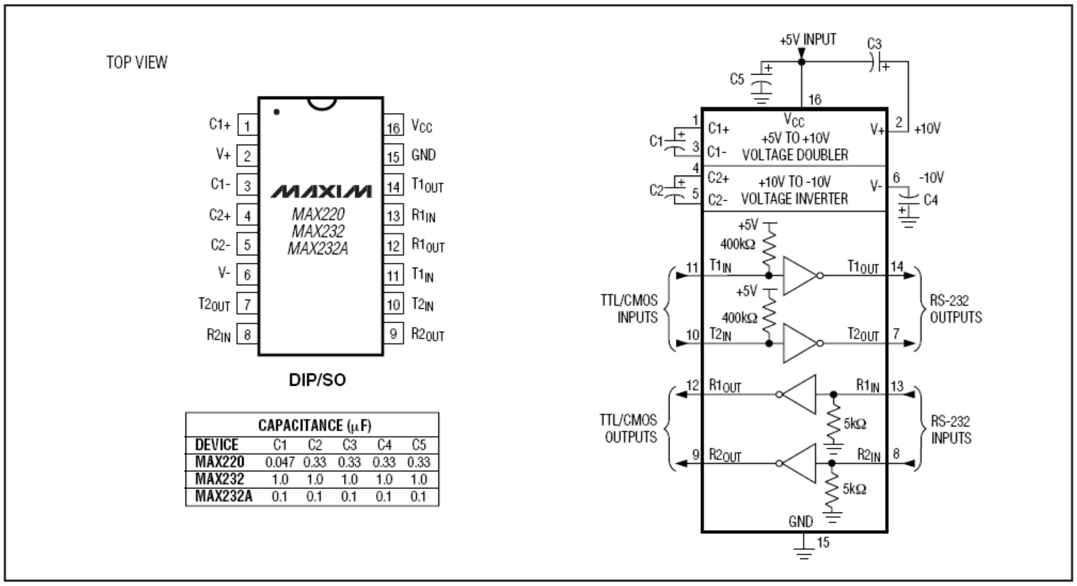

Figure 22: Pin Out Schematic of the MAX232

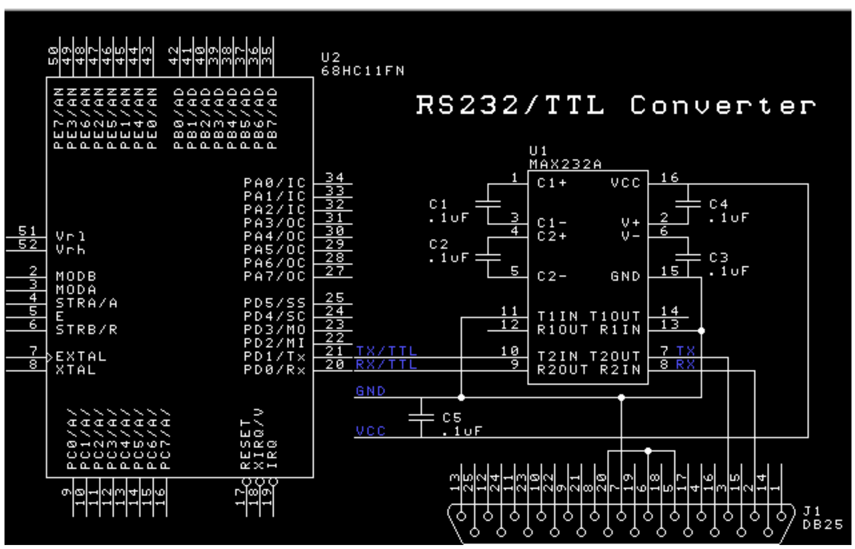

Figure 23: Schematic of the RS232–to–TTL Converter

Channel	DE-9 Pin	DB-25 Pin	MAX232 Pin
T2 Out	2	3	7
R2 In	3	2	8
Ground	5	7	GND

B OOPic Pin Outs

Pin	Name	Function
1	LSDA	To WCM_{Pin3}
2	GND	
3	LSC	To WCM_{Pin4}
4	Power	WCM_{Power}
5	Reset	
6	I/O 15	M4_{CCW}
7	I/O 1 ADC	Mux_1
8	I/O 14	M4_{CW}
9	I/O 2 ADC	Mux_2
10	I/O 13	M3_{CCW}
11	I/O 3 ADC	Accel_{xyy}
12	I/O 12	M3_{CW}
13	I/O 4 ADC	Accel_{xyx}
14	I/O 11	M2_{CCW}
15	I/O 5 ADC	Accel_{yzy}
16	I/O 10	M2_{CW}
17	I/O 6 ADC	Accel_{yzx}
18	I/O 9	M1_{CCW}
19	I/O 7 ADC	Pressure
20	I/O 8	M1_{CW}
21	+5 V Reg	Current Sensors on Power PCB
22	+5 V Reg	Compass, Gyros, Accels, Pressure
23	GND	Pressure GND
24	GND	Compass, Gyros, Accels
25	I/O 16	M5_{CW}
26	I/O 31	MDT_1 Digital_{In}
27	I/O 17	M5_{CCW}
28	I/O 30	MDT_2 Digital_{In}
29	I/O 18	M6_{CW}
30	I/O 29	MDT_3 Digital_{In}
31	I/O 19	M6_{CCW}
32	I/O 28	A_2 Mux
33	I/O 20	M7_{CW} & M8_{CCW}
34	I/O 27	A_1 Mux
35	I/O 21	M7_{CCW} & M8_{CCW}
36	I/O 26	A_0 Mux
37	I/O 22	Wireless_{In}
38	I/O 25	
39	I/O 23	Wireless_{Out}
40	I/O 24	[Blown]

C Multiplexer Pin Outs

Mux Input	Mux1	Mux2
1	M1 Current	M2 Current
2	M3 Current	M4 Current
3	M5 Current	M6 Current
4	M7 Current	M8 Current
5	M9 Current	M10 Current
6	M11 Current	M12 Current
7	Gyro$_{Pitch_Temp}$	Gyro$_{Pitch}$
8	Gyro$_{Roll_Temp}$	Gyro$_{Roll}$

D Costs

Qty.	Part	Supplier	Unit Cost	Total Cost
1	Graupner LiPo Charger 4	`hobby-lobby.com`	$29.90	$33.89
3	H-Bridge & Control PCB	Advanced Circuits	$33.00	$109.00
				$142.89

E OOPic Code

```
'Full Surface

Dim M5CW As New oPWML Dim M5CCW As New oPWML
Dim M6CW As New oPWML Dim M6CCW As New oPWML
Dim M7CW As New oPWML Dim M7CCW As New oPWML
Dim M8CW As New oPWML Dim M8CCW As New oPWML

Sub Main()
    ooPIC.Delay = 500

    'Stern Starbord
    M5CW.IOLine = 16
    M5CW.Operate = cvOn
    M5CCW.IOLine = 17
    M5CCW.Operate = cvOff
    M5CW.DutyCycle = 0

    'Stern Port
    M6CW.IOLine = 18
    M6CW.Operate = cvOn
    M6CCW.IOLine = 19
    M6CCW.Operate = cvOff
    M6CW.DutyCycle = 0

    'Bow Starboard
    M7CW.IOLine = 20
    M7CW.Operate = cvOn
    M7CCW.IOLine = 21
    M7CCW.Operate = cvOff
    M7CW.DutyCycle = 0

    'Bow Port
    M8CW.IOLine = 24
    M8CW.Operate = cvOn
    M8CCW.IOLine = 25
    M8CCW.Operate = cvOff
    M8CW.DutyCycle = 0

End Sub
```

```
'Slow Reverse

Dim M1CW As New oPWML Dim M1CCW As New oPWML
Dim M2CW As New oPWML Dim M2CCW As New oPWML
Dim M3CW As New oPWML Dim M3CCW As New oPWML
Dim M4CW As New oPWML Dim M4CCW As New oPWML

Sub Main()
    ooPIC.Delay = 500

    'Upper Starboard
    M1CW.IOLine = 8
    M1CW.Operate = cvOff
    M1CCW.IOLine = 9
    M1CCW.Operate = cvOn
    M1CCW.DutyCycle = 7

    'Upper Port
    MWCW.IOLine = 10
    M2CW.Operate = cvOff
    M2CCW.IOLine = 11
    M2CCW.Operate = cvOn
    M2CCW.DutyCycle = 7

    'Lower Starboard
    M3CW.IOLine = 12
    M3CW.Operate = cvOff
    M3CCW.IOLine = 13
    M3CCW.Operate = cvOn
    M3CCW.DutyCycle = 7

    'Lower Port
    M4CW.IOLine = 14
    M4CW.Operate = cvOff
    M4CCW.IOLine = 15
    M4CCW.Operate = cvOn
    M4CCW.DutyCycle = 7

End Sub
```

```
'Rotate Starboard

Dim M1CW As New oPWML Dim M1CCW As New oPWML
Dim M2CW As New oPWML Dim M2CCW As New oPWML
Dim M3CW As New oPWML Dim M3CCW As New oPWML
Dim M4CW As New oPWML Dim M4CCW As New oPWML

Sub Main()
    PIC.Delay = 500

    'Upper Starboard
    M1CW.IOLine = 8
    M1CW.Operate = cvOn
    M1CCW.IOLine = 9
    M1CCW.Operate = cvOff
    M1CW.DutyCycle = 7

    'Upper Port
    M2CW.IOLine = 10
    M2CW.Operate = cvOff
    M2CCW.IOLine = 11
    M2CCW.Operate = cvOn
    M2CCW.DutyCycle = 7

    'Lower Starboard
    M3CW.IOLine = 12
    M3CW.Operate = cvOn
    M3CCW.IOLine = 13
    M3CCW.Operate = cvOff
    M3CW.DutyCycle = 7

    'Lower Port
    M4CW.IOLine = 14
    M4CW.Operate = cvOff
    M4CCW.IOLine = 15
    M4CCW.Operate = cvOn
    M4CCW.DutyCycle = 7

End Sub
```

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