BCIT Mechanical Engineering

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Summary

The BCIT ROV Team first started the submersible Remotely Operated Vehicle (ROV) project in January 2008. The first obstacle that the team had to overcome was effective communication, as the work was being completed by three groups within the ROV Team. This required a lot of patients in order to work “as one”. The initial brains storming and design phase began well and lead to many tangible options, however after many hours of analysis and redesigning, the final setup was chosen. The completed ROV is a bare bones vehicle that is meant to be simple and very functional. The Team kept to the motto: “Keep It Simple” (K.I.S.) and the proof is in the ROV. The lava sample retriever is a simple rake mechanism with minimal moving parts which also doubles as the arm that will be used to free the O.B.S.; while the temperature sensor is a relatively simple electronic circuit that can provide more than enough accuracy to achieve our goals while not being overly complicated. The motors and control system were also designed from scratch and made to be reliable. These components finally come together into one package that functions seamlessly.

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1.0 Thrusters

The problems from the previous designs have been considered when this final design begins. The major changes from the second prototype design are as following:

1.1 Sealing

The design of waterproofing and sealing had been changed into three components:

1. An aluminum seal cap
2. A 4 mm inside diameter oil seal
3. Grease

The purpose of the aluminum seal cap was to hold the oil sea and to be filled with grease. The design of the seal cap was based on the outside diameter of the oil seal. Since the seal was press-fitted into the hole, the cap held the seal securely. Therefore, the clearance between the cap hole and the seal was very small so it would increase the strength to hold the seal. The cap was made of aluminum due to easier manufacturing and the non-corrosion in the chlorinated water.

To place the cap properly and firmly in the center, the cap was held onto the motor with threads that are already used by motor. Because the thread holes on the motor were designed to be aligned with the motor shaft, the seal cap will placed properly in the center along with the motor shaft.

From the second prototype design, the two oil seals created a significant surface friction on the motor shaft and the extension shaft. Instead of putting two oil seals, only one oil seal would be placed into the aluminum seal cape in the final design. The oil seal was placed outside of the end cap because it would prevent water leaking into the motor.

When the seal cap is filled with grease, it will help lubricate the shaft and seal. It will also prevent water leaking into the motor. Since grease is not liquid, it is thicker than hydraulic oil. Grease will not leak out once the motor started to turn.

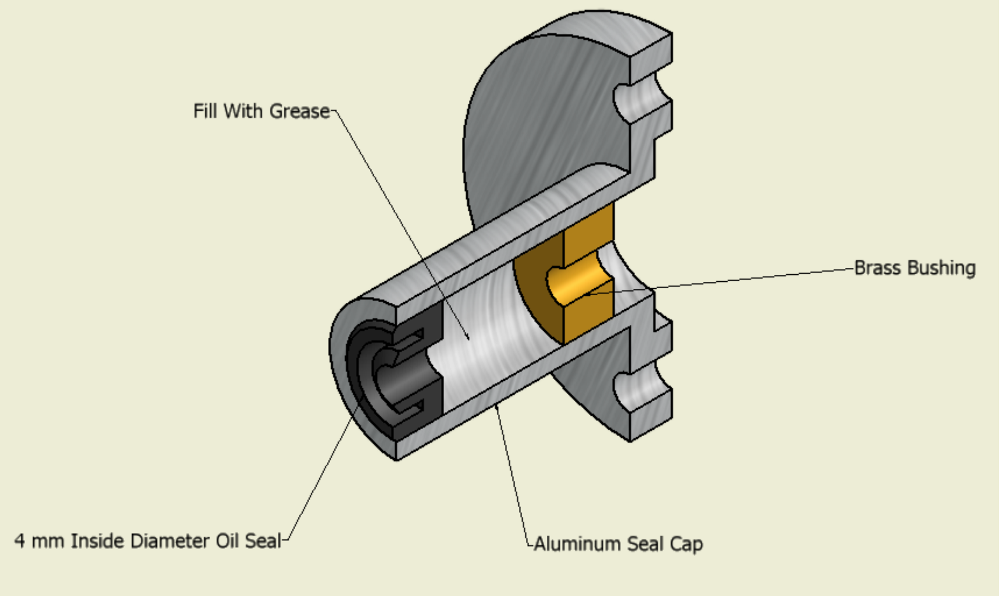


Figure 1: Motor End Cap w/ Sealing

In Figure3, the sealing was in double layer form. If the seal had worn out due to motor shaft, the water would not leak into the shaft because of the grease.

1.2 Shaft oscillation

Although the motor shaft rotated perfectly in the center, the extension shaft from the second prototype thruster created oscillation due to the manufacture error. If oscillation occurs while the shaft is rotating in the water, it will break the motor eventually. Furthermore, the oscillating shaft creates larger gaps between the shaft and the seal. In the end, the oil seal would break apart and the thruster would leak. Because the propeller could not be press-fit onto the motor shaft, the propeller adapter was designed to thread into the propeller. To prevent extended shaft from oscillating, the shaft was redesigned to form a shorter propeller adapter. However, oscillation of shaft and propeller still occurred when the motor runs in water.

Figure 2: Propeller / Adapter / Seal Cap

To make sure the shaft is rotating in the center under the water, a brass bushing was designed to decrease the shaft from oscillating.

1.3 Shape of the thruster

To create a better water flow, the shape of the thruster was designed into a cylinder shape. Compared with the hydrodynamic shape, the cylindrical shape creates larger drag force under the water. Drag force decreases the movement of the ROV and it also decreases substantial amount of the thrust. The more the drag force a thruster has, the slower the ROV.

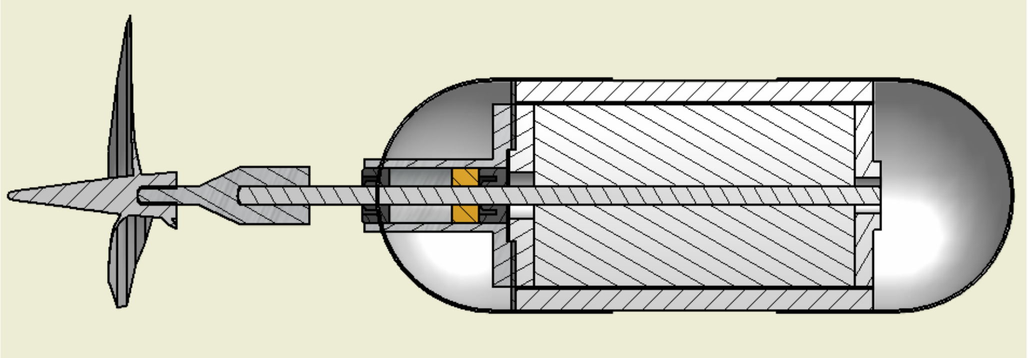


Figure 3: Final Design Shape

The drag force also depends on the cross-section area of the thruster. If the shape of the thruster is cylindrical, the drag force in the water increases. However, the drag force decreases which provides better movement in water if the shape of the thruster is in pill shape or hydrodynamic shape.

1.4 Nozzle

The purpose of a nozzle around the propeller is to increase the amount of thrust underwater. Also, the nozzle provides more sensitive movements under the water. If the propeller starts to turn under the water, the nozzle will provide protection around the propeller. Once the propeller starts to turn and provides thrust, the thrust and water flow after the propeller will be unstable. This situation causes cavitations that will cause the shaft to oscillate.

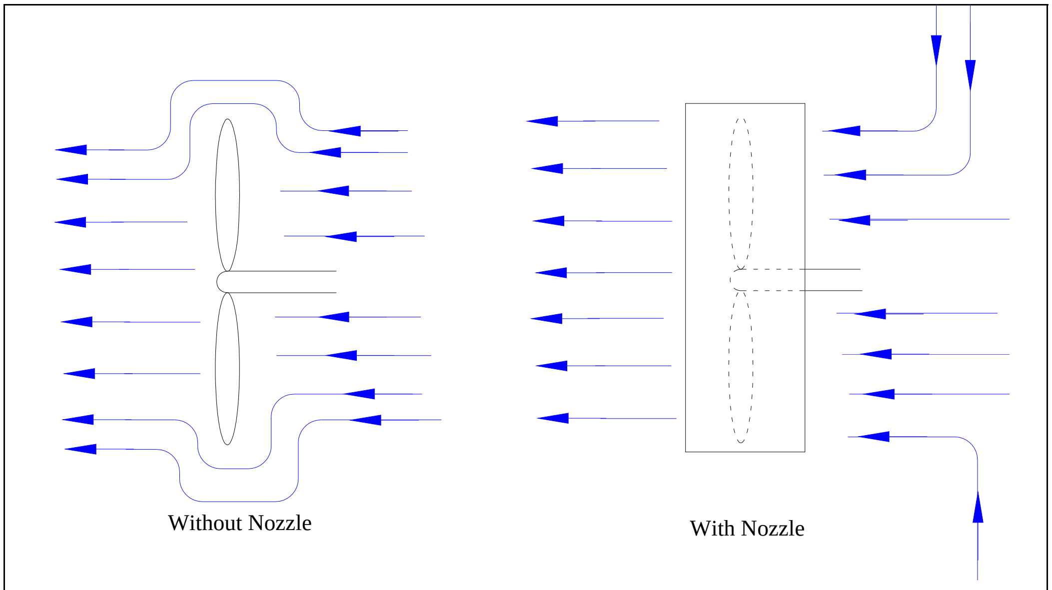


Figure 4: Comparison of Thruster with and without Nozzle

To prevent cavitation and shaft oscillating, the nozzle makes the thrust more stable and focus in one direction.

1.5 Electrical Wires

Sealing the connection of the electrical motor was hard due to housing of the thruster that could not cover the connection. Furthermore, the connection was very fragile and weak. Loose connections between the motor and wires were created with any movements or oscillation around the connection. Therefore, the unbalanced electrical power would be delivered and provided unstable thrust.

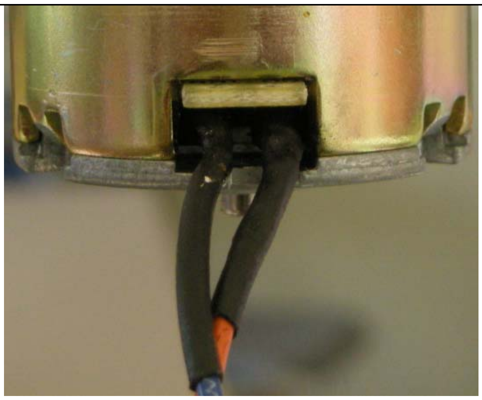


Figure 5: Electrical Motor Connection

In Figure 9, the black electrical cap from the original motor was removed completed so the housing could be assembled on to the motor easily. In the modified motor, the wires were soldered separately inside the motor instead of using electrical cap to connect the wires. Then, heat-shrinks were put in the motor to cover the raw surface of connections.

1.6 Waterproofing

The final design was fully waterproofed in 12 feet deep water. According to the pervious prototype thrusters, the areas where the water leaked into the motor were:

1. Extension shaft to the seal
2. Electrical connections

Since the motor shaft and the adapter were rotating smoothly at the center, no oscillation occurred to deform the oil seal. In other word, since oil seal did not deform, the inside diameter of the oil seal stayed the same diameter. Therefore, water would not leak into the motor from the extension shaft.

After the electrical connection of the motor was completely modified, the end caps of the thruster could easily cover the connection and waterproofed it. However, to connect the wire back to the circuit board, two holes must be drilled at the nose cap of the thruster.

1.7 Water flow

By experiments and calculation, the drag force in cylindrical shape was definitely larger than the one in hydrodynamic. The larger the drag force is, the harder for the thruster moved. A smoother water flow pattern occurred with hydrodynamic shape than cylindrical. Therefore, less surface friction would be needed and the thruster would be able to maneuver more smoothly under water.

2.0 Frame and Controls

The duties of the control unit that was designed is to provide control signals to drive 5 thrusters, produce an on/off signal to control the tooling, interface with a temperature sensor and send/receive data with the laptop computer being used to pilot the ROV.

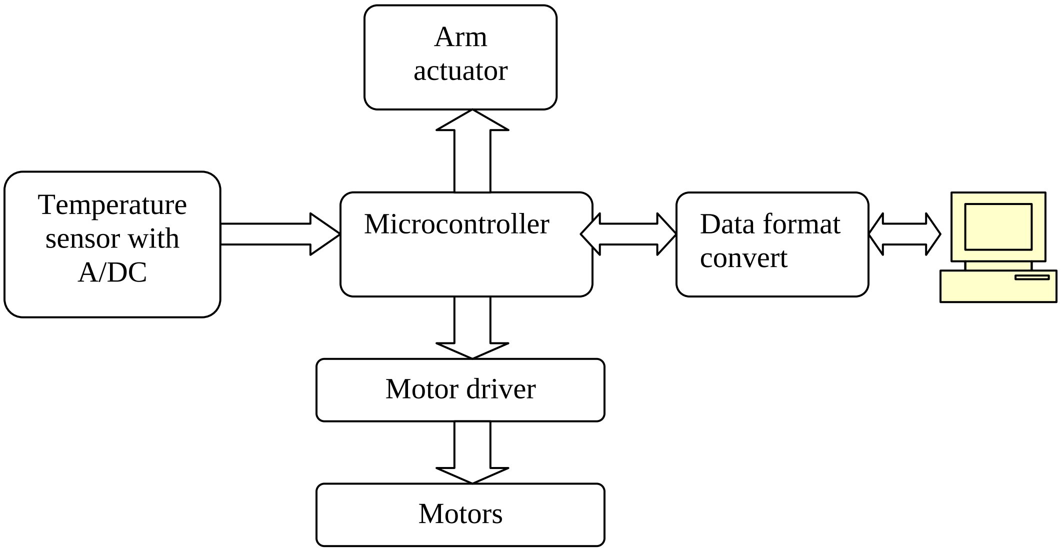


Figure 6 : Control Diagram

2.1 Microcontrollers

A microcontroller system has been used in our project. This was used mainly owning to its low cost and it being relatively easy to program. Also, microcontrollers have the ability to output a digital signal, so that communication with a laptop computer is possible.

Several microcontrollers with the same functionality are available. Originally the 89S52 from Atmel Corporation had been chosen for use in this project. The 89S52 is an 8051 architecture 8-bit, MCS-51® industry standard socket drop-in device, In-System Programming capability microcontroller. The reasons for choosing the 89S52 were:

1. 89S52 has 40 pins (4 I/O port), so 32 programmable control line is available.
2. 9S52 has DIP (Through Hole Mount) package, so PCB can be produced in BCIT lab rather than purchase a prebuilt PCB.
3. 89S52 is an In-system Programmable microcontroller. This means the program can be downloaded on board. This would allow for easy re-programming and debugging.

The PCB's were designed, manufactured and the program was written. However this microcontroller was not used. In order to de-bug the program a simulation circuit board was required, and the team did not have access to such equipment. Luckily, our sponsor had access to a different microcontroller that came with the simulation equipment. In order to get our ROV ready for the qualifying in Seattle, a new PCB, and program was designed and manufactured in record time.

The new microcontroller used was the PIC16F917 from Microchip Technology Inc. Not only does this microcontroller share the same qualities of the first controller, it also has an internal crystal so it can provide an 8 MHz internal clock and is has a smaller reset circuit and program interface.

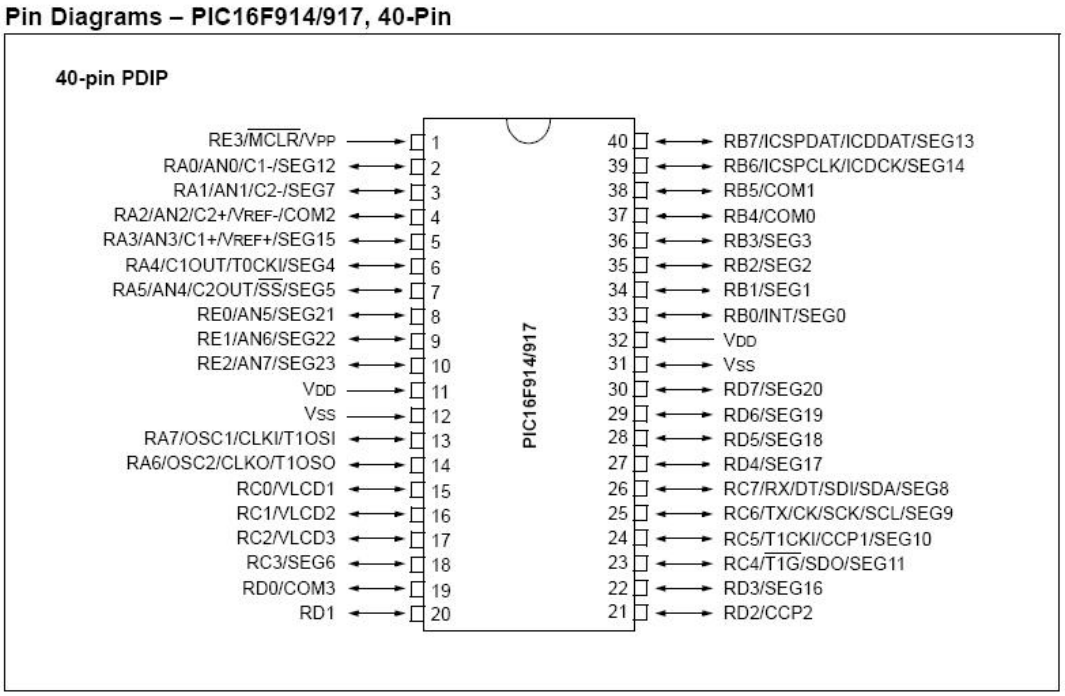


Figure 7: I/O Diagram for PIC16F917

2.1 Circuit Board Design

Number one priority was to make all parts of the circuit compatible with the microcontroller. The first circuit required is a voltage step down circuit, which consists of a MAX667 chip that will reduce the 12 volts being provided by the tether to a usable 5 volts that is required by the microcontroller. The Max667 is a linear voltage regulator that will supply up to 250mA of output current. Another required circuit is the data converter that will convert output from the microcontroller into RS485 so the signal can travel the long distance of the tether. The laptop will not detect the RS485, so another circuit is used to convert the RS485 to a recognizable RS232. To convert the data to RS485, the MAX488 chip is used. To convert the RS485 signal the MAX232A chip is used.

2.2 Printed Circuit Boards

All PCB's used on the ROV were designed and manufactured completely by the frame and controls team in the BCIT SW9 electronics shop. To design the circuitry the program EZ-Route 2000 was used. To manufacture the PCB the following steps were taken :

1. Laser Print the circuit onto paper
2. Use an heated press to transfer the ink onto the board
3. Remove the paper from the board with water, leaving only the ink
4. Acid etch the board. (The ink protect the board, and leave the circuit behind)
5. Use acetone to remove the ink
6. Use liquid tin to outline the circuit to allow easier soldering and prevent corrosion
7. Solder all parts onto the board

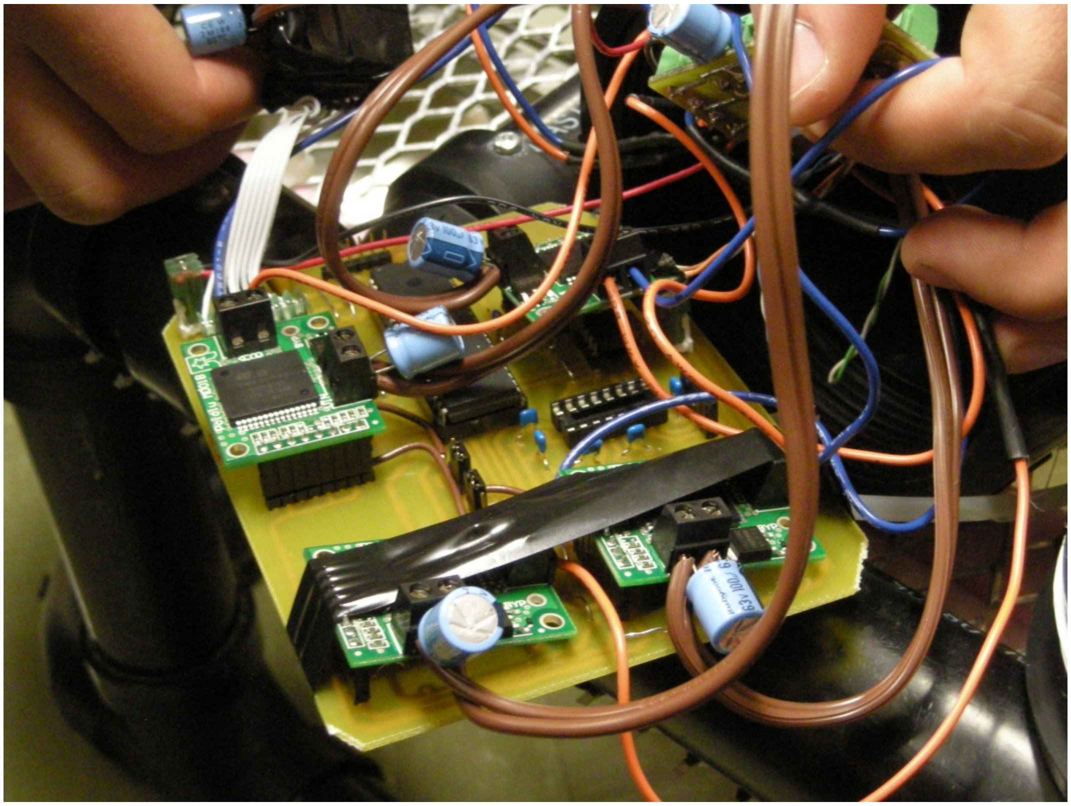


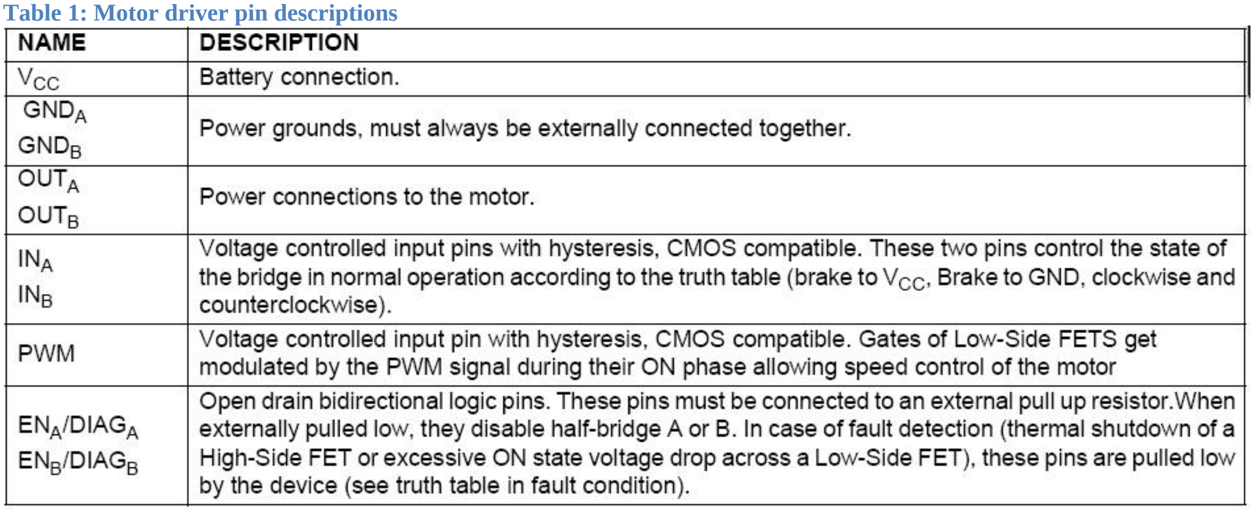
Figure 8: On-board PCB with attached motor drivers and power BUS

A third PCB was designed to distribute the 12v and 24v power from the tether. It worked as a BUS. It has 12v and 24v power from the tether coming in and shares a common ground. From this BUS, it delivers 12v to the voltage regulator and 24v to each motor driver.

2.3 Motor Drivers

High current integrated H-Bridge circuits were used to help keep the on-board control circuits as compact as possible. The circuit chosen is manufactured by Pololu. Each thruster will require one h-bridge circuit. Pulse Width Modulation (PWM) is being used to vary the speed of the motors. PWM varies the speed of the motors by pulsing a signal to a transistor in the h-bridge circuitry. This transistor turns the supply voltage on and off to the motors. The rpm of the motor is modulated by the PWM depending on the duty time of each cycle. The on board controls for the ROV have the ability to control five bi-directional motors with PWM.

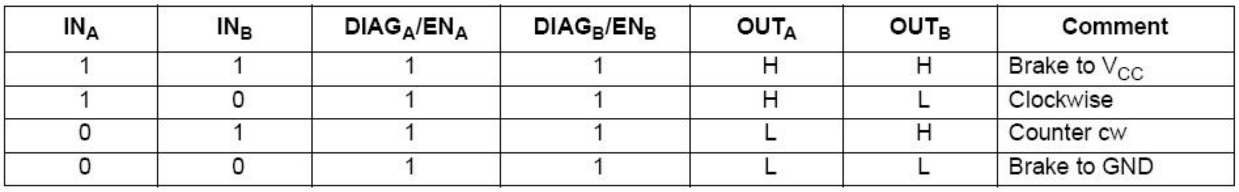
Table 1: Motor driver pin descriptions



NAME	DESCRIPTION
V_{CC}	Battery connection.
GND_A GND_B	Power grounds, must always be externally connected together.
OUT_A OUT_B	Power connections to the motor.
IN_A IN_B	Voltage controlled input pins with hysteresis, CMOS compatible. These two pins control the state of the bridge in normal operation according to the truth table (brake to V_{CC}, Brake to GND, clockwise and counterclockwise).
PWM	Voltage controlled input pin with hysteresis, CMOS compatible. Gates of Low-Side FETS get modulated by the PWM signal during their ON phase allowing speed control of the motor
$EN_A/DIAG_A$ $EN_B/DIAG_B$	Open drain bidirectional logic pins. These pins must be connected to an external pull up resistor.When externally pulled low, they disable half-bridge A or B. In case of fault detection (thermal shutdown of a High-Side FET or excessive ON state voltage drop across a Low-Side FET), these pins are pulled low by the device (see truth table in fault condition).

There are 8 pins connected to the on-board PCB, but only 7 pins are useful, because the CS pin doesn't connect to anything. The pilot of the ROV has control over the INA, INB which will change the direction the motor will rotate.

Table 2: Motor driver truth table



IN_A	IN_B	$DIAG_A/EN_A$	$DIAG_B/EN_B$	OUT_A	OUT_B	Comment
1	1	1	1	H	H	Brake to V_{CC}
1	0	1	1	H	L	Clockwise
0	1	1	1	L	H	Counter cw
0	0	1	1	L	L	Brake to GND

2.3 Tooling Related Controls

2.3.1 Arm Control

The tooling team required the control system to be compatible with the tooling they were designing to carry out the mission tasks. A pneumatic cylinder is being used to control the arm that will collect the lava samples. A MAC 45 series solenoid actuated pneumatic valve was selected by the tooling team to control the pneumatic double acting cylinder. The valve requires a 24 volt signal to actual the solenoid, however the microcontroller can only provide a 5 volt signal. To remedy this voltage difference, a MOSFET transistor will be used to boost the control signal.

2.3.2 Interface with temperature sensor

Since the output of temperature sensor is an analog signal, which cannot be recognized by microcontroller, ADC (analog to digital convertor) has been used to convert the analog signal to digital signal. Therefore, an I2C protocol (Inter-Integrated Circuit) must be used. Three I/O pins (clock, data and chip select) can perform that function. Six modes of protocol are available; mode 5 is the one has been used. I2C is a multi-master serial computer bus that was developed by Philips. Its main purpose in our application is to attach the temperature sensor to the microcontroller.

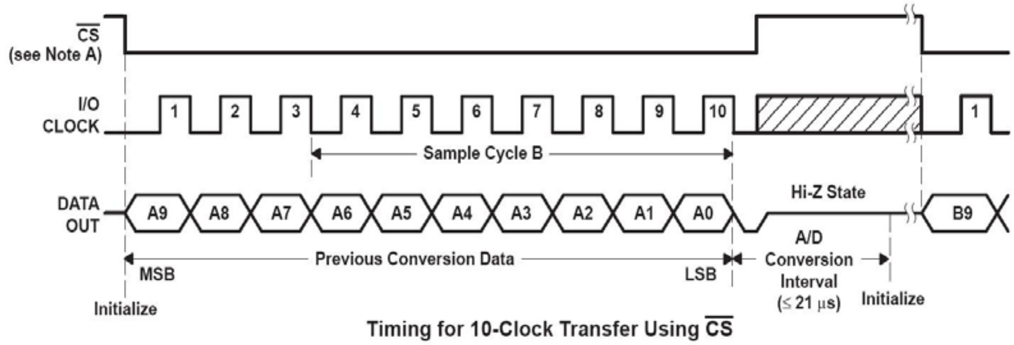


Figure 9: Temperature Sensor

2.4 Programming the Microcontroller

C was the programming language chosen to program the on board microcontroller. C is the most common language used to program firmware however it is difficult to learn. Luckily a member of the team already knew how to use the C programming language, and our sponsor also offered technical support. At this point in time, the controller is programmed, however there will be some changes made when a new controller joystick is added to ease the piloting of the ROV.

The program that was produced is very basic. It is all about setting the registers and changing the value of the pins. The first part of the program is setting the registers. What this does is set up the microcontroller to transmit and receive the signals coming from the laptop. It also assigns the pins to either input or output on the microcontroller.

For example:

To Setup the PWM Module:

```
TRISD &= 0b00001011;
TRISC &= 0b11011111;
TRISB &=0b11111100;
PR2 = 0x65;
```

This code will change the registers so the microcontroller can run properly with the correct inputs, outputs and PWM modules. The compiler software used to download the program to the microcontroller is the HI-TECH C PRO for the PIC10/12/16 Family. This was used because it was specifically designed to be compatible with the chip that was decided upon.

2.5 Piloting the ROV

The ROV uses a five thruster arrangement to maneuver under water. There are two vertical thrusters, two horizontal thrusters and one thruster for “crab walking” or “strafing”. To turn, the ROV the rear thrusters will provide the power. For example, to turn to the left or “port” side, the right, or “starboard” thruster will be at full forward power, while the port thruster will be full reverse. Alternatively, to turn to the starboard side the port thruster will be at full forward power, while the starboard thruster will be at full reverse power. By having the two thrusters oppose each other, a sharper turning radius will be generated.

The controls for the ROV are currently all done through a laptop keyboard. To set the PWM duty cycle for bow, stern, port and starboard movement, the numbers one through zero are used. Each number multiplied by ten is the percentage of total power available. For example, the number two would send twenty percent of all power.

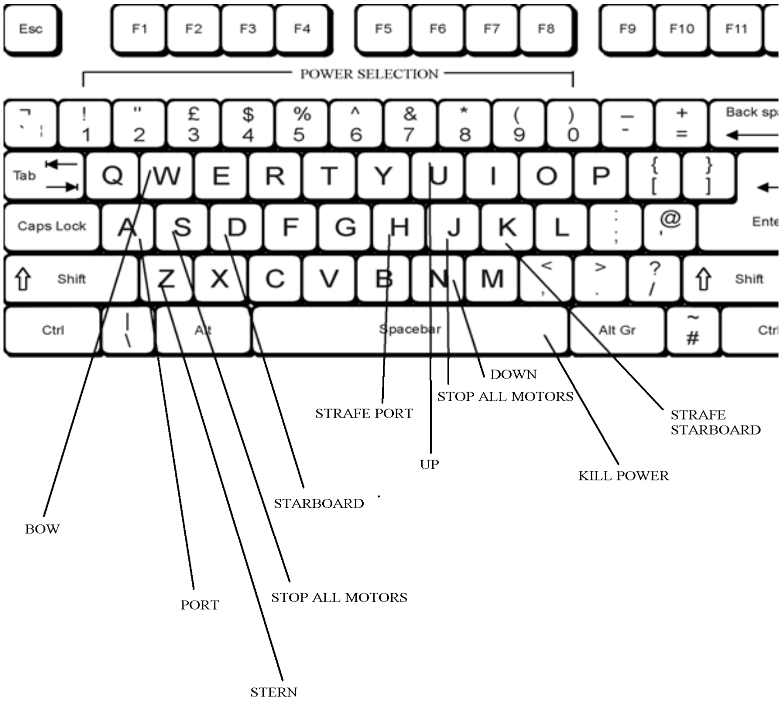


Figure 10: Keyboard Controls

The keyboard controls are only temporary, and have been used only during the qualifying due to lack of time to complete a circuit for a joystick. Once final exams are over, a new circuit will be designed to give the pilot greater control over the ROV.

2.6 CAMERAS

MATE rules state that a maximum of three monitors may be used at the control station. At this point in time it is anticipated that only two cameras will be used in the competition. There will be one camera mounted to the top tube at the bow of the ROV to provide a view of the tooling envelope. This camera will also provide the main view while maneuvering to the mission site. A second camera will be mounted to give a view of the tooling being used to obtain a temperature reading from the hydrothermal vent. This position is still undetermined as the placement of the tooling is still undecided by the tooling team. To transmit the video images, a CAT-5 communications cable will be used. Because there are no lighting restrictions in this year’s event, color cameras will be used. The cameras will be nitrogen purged to ensure no condensation builds up in front of the lens while operating in cold water. They are safe to use up to 15 meters. No cameras have yet been mounted to the ROV.

2.7 BALLAST

Task two requires the ROV to load three, two pound weights and return to the surface with them. The added six pounds of weight will only allow a maximum thrust of two pounds to propel the ROV to the surface. In order to combat this effect, and save precious time returning to the surface, a ballast system

The ballast system will consist of two air tanks, two valves connected by standard fittings and hoses. The tanks will be constructed from 4 inch ABS pipe with end caps and an opening 1 inch wide down its length. The valves will be 2/2 Normally Closed, solenoid actuated with spring return, the valve sourced for this application is a MAC 45 Series. This was chosen for its optional balanced poppet that is resilient to pressure changes, its short stroke with high flow and its strong return spring. The power source will be an above surface compressor, with the regulator set at 40psi. Standard fittings with a 4mm ID will be used on both tanks.

To activate the ballast, a 24volt control signal will need to be sent to activate the solenoid. Because the ballast will only be large enough to provide the exact amount of force to return to the surface, it requires the operator to just activate the ballast continuously until the ROV returns to the surface. This is possible because there is no danger of overfilling the tank. The position of the ballast will be on the top tubes on the port and starboard sides. The centroid of the buoyant force will be corresponding to the center of the combined force from the dive weights.

There is no plan to manufacture the ballast system until the ROV is fully functional, as the ballast will only improve the overall speed of the run and not help with the initial construction.

2.8 Tether

The tether supplies all of the power, compressed air and provides communication from the on-board microcontroller to the laptop. The motors that have been chosen, run off of 24 volt power and draw a maximum of 4 amps during normal operating conditions. The controller runs off of 5 volt power, and a step down circuit is in place to take 12 volts from the tether and supply the necessary five volts. MATE rules limit the ROV to drawing a maximum of 40 amps of current at 48 volts and can only use a maximum air pressure of 40 psi to power the double acting cylinder. With these requirements and rules it was decided the following materials be used.

- 20 meters of extension cord [3x14 gauge]
- 2 x 20m of 4mm pneumatic hose
- 20 meters of CAT-5e communications cable
- 2 x Inline fuse holders
- High density foam for buoyancy

Extension cord was a logical choice owing to the fact it is capable of carrying 14 amps of current per wire, which will supply the motors without going over its rated capacity. It also is very flexible and is coated with rubber. The rubber will ensure no damage will occur to the power lines while the ROV is operating. The pneumatic hose will provide some, but not all of the required buoyant force to keep the tether neutrally buoyant and was specified by the tooling team. The CAT-5e is an outdoor communications line that has a durable outer wrapping that will keep the 4 twisted pair wires inside safe from damage.

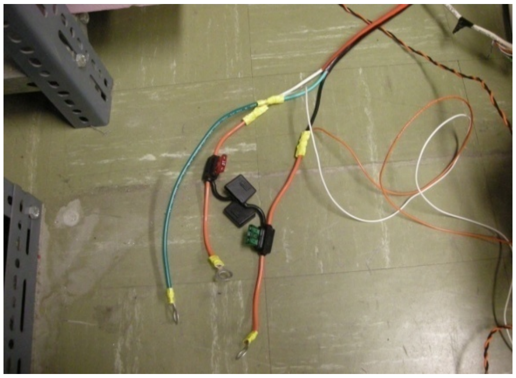


Figure 11: Inline Fuse

The fuse holders are 12 gauge wire, and are at the ends of the extension cord. One is placed on the 24 volt line, the other is on the 12 volt line. The 24 volt line has a 30 amp fuse in the holder, and the 12 volt line has a 10 amp fuse in the holder. To connect the power lines to the power source, 3/8" ring connectors are crimped onto the ends of the inline fuse holders and onto the end common ground wire. To connect the CAT-5e cable to the above water circuit board, a four pin connector is used. To connect the above water circuit board to the laptop a DB9 to USB adapter cable is used.

At the bottom side end of the tether the CAT- vo
pneumatic lines connect directly to the double be
required when the ballast system is installed.

2.9 Control Housing

The bottom side circuit board must be kept dry at all times. In order to ensure this happens, a water-proof housing was constructed from ABS pipe fittings. It consists of a 4” ABS coupling, two threaded 4” end pieces, two ABS threaded end caps and a 1” PVC threaded attachment. Four inch pipe was chosen as it is the exact width of the PCB. The PCB sits in the middle, while the wiring can be routed above or below it. A one inch hole was drilled and tapped with a 1-2-UNC thread in one end cap. The 1” PVC threaded attachment was then screwed into the cap to provide a route for the tether wires to attach to the PCB. The wires were all fed through the cap and then secured on either side with a zap-tie to prevent the wires from pulling out. Then an automotive RTV sealant was used to waterproof the wires entrance to the housing. RTV sealant was selected for its durability and ability to cure very quickly. The couplings and end pieces were adhered together using the same solvent that was used to manufacture the frame. RTV sealant was used on all joints. The housing will provide a buoyant force of 2.726 pounds.

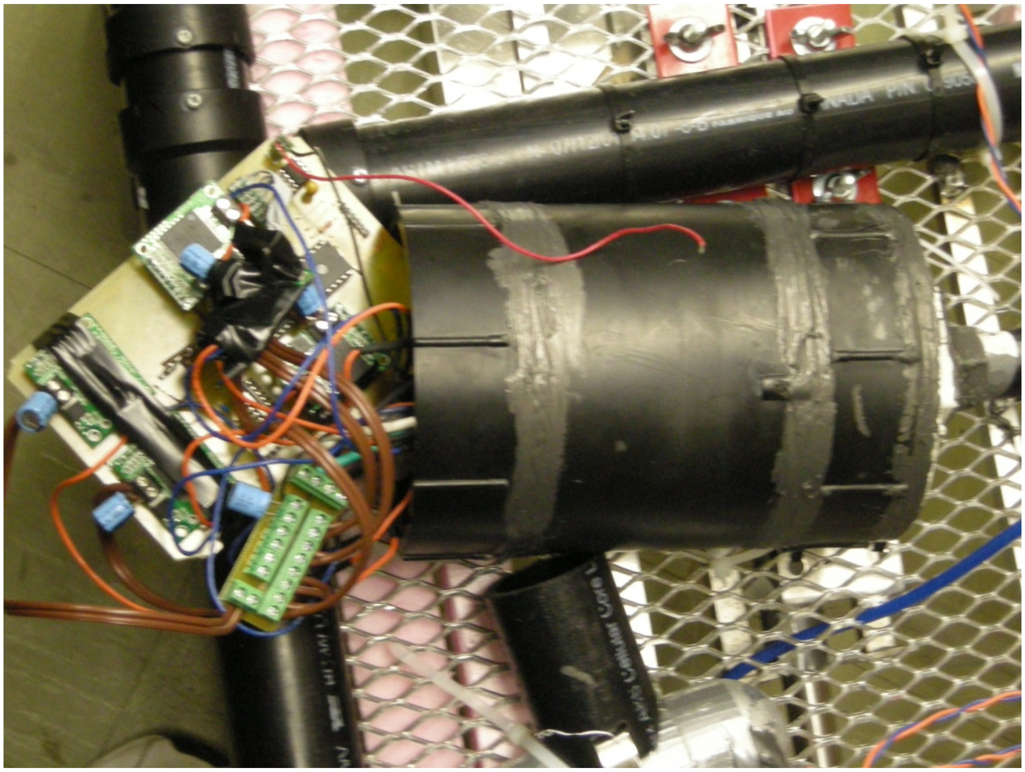


Figure 12: Waterproof Controls Housing

3.0 Task Specific Tooling

3.1 Manipulator

A wide variety of manipulator concepts were generated during the brainstorming phase of the design. Initial designs suggested using a manipulator that would be able to move with several degrees of freedom to pick up and maneuver samples in order to deposit them into a storage container onboard the ROV.

The final design differs from the original design in many ways. The two most significant changes were in the manipulators mobility (which was greatly reduced) and also changing the intended power source from hydraulics to pneumatic due to economic reasons. While researching and designing many changes have been made to the final product, such as reducing weight, and maximizing the adjustability of the rake.

The following considerations were made during the design of the rake:

- Power source
- Construction / Operation
- Mount to frame

These three considerations played the most important roles in the Manipulator design as they all interconnect and must work in harmony for the overall tool to function properly with the completed ROV.

3.1.1 Power Source

Three power options are available to use for the tooling needed on the ROV, hydraulics, electrical, and pneumatic. MATE limits the power to 48 Volts / 40 Amps electrical, 150 psi hydraulic and 40 psi pneumatic. During the brainstorming and initial design phase, the intended power source was hydraulic; however, after more research it was not seen as a viable option due to high cost, and heavy construction. Electric motors were considered, but were rejected because of foreseen difficulties in water proofing.

Finally, a pneumatic power source decided upon, such that the air will not contaminate the water and the components required are within our budget and size restrictions. Along with being clean, using a pneumatic system adds approximately 0.223 lbf of buoyancy, slightly compensating for the added weight of the samples. A pneumatically operated manipulator is lighter than the other options considered, thus reducing the overall weight of the ROV, and increasing maneuverability by making the tether smaller and more flexible.

The compressed air will be supplied via an air compressor on the surface at pool side providing compressed air at 40 psi. Initially the air was designed to be vented at the ROV, however due to the ROV operating at depth there is a backpressure on the exhaust port. The amount of loss in operating pressure at 10 ft deep is 4.33 psi, changing the system pressure to 35.67 psi. In order to compensate for this, it was decided to use a supply line and a return line therefore minimizing the pressure loss. The amount of force produced by the cylinder on the extension stroke is 15.76 lb while the retraction stroke produces 7.0 lb of force. The estimated force to pull one weight is 0.6 lb, which is considerably less than what is provided.

3.1.2 Construction / Operation

All parts constructed in house are made of aluminum to minimize weight and also because of aluminum’s corrosion resistant properties. The manipulator was designed around simple functionality, and minimizing the amount of movement of the rake. The rake is hinged allowing it to pass over a sample during the extension stroke, and becoming rigid while retracting. This simple design allows the rake to pull the sample inside the ROV. Once inside the ROV the samples will sit on a scoop containing them until they are brought to the surface. The scoop is an aluminum container with three sides, and is open in the front to allow the samples to be brought onboard. To keep the samples within the ROV, the arm is retracted and acts as the fourth side enclosing the container. The arm has the ability to be adjusted by shimming the mounting brackets, or adjusting the rake angle screw to raise or lower the rake end.

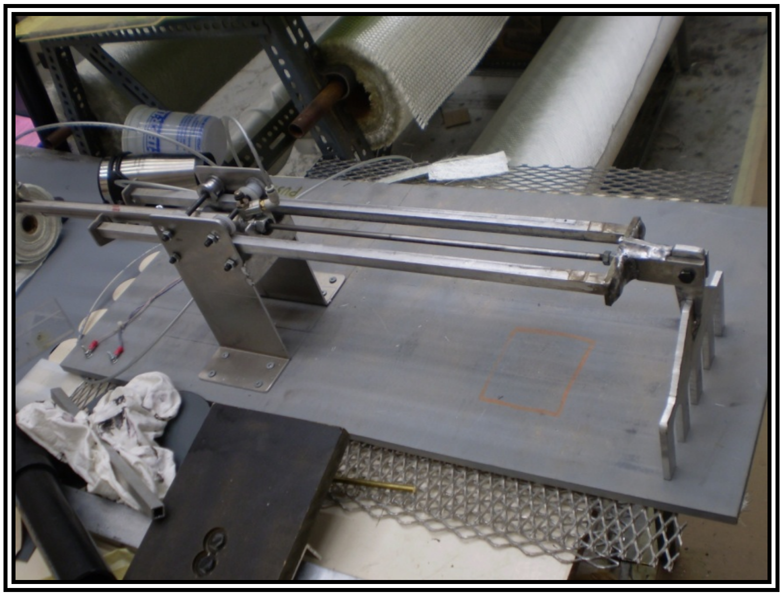


Figure 13: Complete Arm assembly before mounted to ROV.

Figure 26 shows the complete arm assembly before mounted in the ROV. In the picture the arm is mounted to a piece of plywood which was used to test the arm.

3.1.3 Mounting to Frame

The arm is to be attached to the frame of the ROV; thus, achieving a rigid connection. The arm is to be positioned in the center of the ROV while keeping the rake end aligned with the front of the ROV. Two ½” pieces of square tubing run length wise along the ROV; the tubing provides extra rigidity as well as keeping the arm from twisting during operation. An extra cross member was added on the frame which will serve as the mounting place for the arm. Two U-blots run over the cross member and through the ½” tubing which is then connected to the arm mounting plates. To adjust the height of the rake off of the pool bottom, shims can be added or removed from between the arm mounting plates and the ½” tubing. To adjust the rake inclination, an adjustment screw was added to level the rake once the manipulator is mounted to the frame.

3.2 Pneumatic Valve

3.2.1 Requirements

Two of the tasks the ROV must perform involve physical manipulation of objects underwater. The tooling group decided to use a pneumatic (compressed air) cylinder to provide power to the manipulator. Based on concepts learned in the fluid power courses at BCIT a set of criteria was generated.

The valve needed two pneumatic connections to deliver power to each side of the double acting cylinder. In order for the ROV operator to utilize the manipulator, he or she must be able to switch the power delivery from one port of the actuator to the other. Pressure building on the opposite end of the actuator must be connected to vent. The valve must also be able to operate with a pressure source of only 40 psi.

3.2.3 Selection and Implementation

During the 2008 BCIT careers fair, Skeans Compressed Air Products was contacted with the completed criteria list. Paolo Pagnotta responded with an email in which he identified a valve that was cheaper than any of the other valves that were researched and the valve also met all of the requirements. The valve that he recommended was the MAC 45 series 4/2 valve. The valve part number is MAC-45A-AA1-DDAJ-1KA. This valve is small and as a result is also relatively light weight. It is activated by a direct operating solenoid allowing it to function at low pressures such as 40 psi. The solenoid requires a 24V DC signal, which is the same voltage that is being used for the ROV thrusters. The valve is then attached to an air supply on the surface using two pneumatic lines in the tether. The solenoid is connected to the microcontroller so that the operator can select which port is to be pressurized and which one is to be exhausted.

To avoid the damping effects of having long pneumatic lines between the valve and the cylinder, it was decided to mount the valve on the ROV. Due to possible problems with water entering the valve or pneumatic lines, it was decided to use two pneumatic lines in the tether. One of the lines is for the pressure source and the other for exhausting to the surface. There were concerns that if the valve was exhausted into the water that water might flow back into the open lines. Since the valve will be operating underwater it must be waterproofed. Similar to the temperature sensor circuit board, the valve will be mounted inside of an airtight pipe with a removable end cap so that the valve can be accessed for maintenance. Custom fittings will be manufactured to allow the pneumatic lines to pass through the housing the valve is mounted inside and remain water tight. The pneumatic hose fittings shown above in figure 8 were used at all locations where the hose is connected to components, providing a quick release if need to remove the hose.

3.3 Temperature Sensor

3.3.1 Background and Research

One of the tasks for the competition the ROV is being entered into requires it to determine the temperature of a simulated black smoker (a type of hydrothermal vent) at the bottom of a pool that is approximately 2.5 m deep. The operator of the ROV must be able to see a temperature reading from the surface for fluid flowing out of the top of a thermal vent. The thermal vent will expel fluid between zero and fifty degrees Celsius and will approximately be in the form of figure 6 below.

Initial research yielded five possible options for temperature sensors including thermometers, thermocouples, thermistors, resistance temperature detectors (henceforth RTD), and integrated circuit sensors (henceforth IC sensor). Information from datasheets and from *“The Temperature Handbook”* indicated that each type is suitable for different applications.

3.3.2 Integrated Circuit Sensors (IC Sensor)

Although their response time is relatively slow, IC sensors are highly linear, have high output, and are

Quanitity	Description	Cost	Total
1	4/2 Way spring return pneumatic valve	$34.95	$34.95
1	3/4" X 14" Pneumatic Cylinder	$19.99	$19.99
8	4 mm Push in hose connector	$1.99	$15.92
4 ft	4 mm Pneumatic hose	$0.50	$2.00
19"	1" x 0.25" Aluminum Bar	$1.69	$32.11
0.25 sq ft	0.25" Thick Aluminum Sheet	$20.00/sq.ft	$5.00
1 sq ft	0.125" Thick Aluminum Sheet	$17.00/sq.ft	$17.00
42"	0.5" x 0.5" Aluminum Tubing (1/16" Wall)	$4.50/ft	$15.75
8"	1" Dia Aluminum Round Stock	$10.00/ft	$6.67
20	Assorted Nuts and Bolts	$0,20	$4.00
30 ft	CAT-5e cable	$19.04	$19.04
1	Extension Cord	$44.75	$44.75
30 ft	Pneumatic Line	$40.77	$40.77
10	Fuses and Fittings	$19.89	$19.89
100	Zap-Ties	$3.33	$3.33
30 ft	1 ½” ABS Pipe	$26.01	$26.01
20	ABS T-Joint	$19.92	$19.92
20	Hose Clamps	$20.91	$20.91
1	Controls Case	$28.81	$28.81
1	Atmel Microcontroller	$3.29	$3.29
5	Motor Drivers	$164.33	$164.33
-	PCB and wire connectors	Free	Free
1	MAX Chips	$19.44	$19.44
			$563.88

inexpensive. Initially it was decided to use an RTD for its relatively fast response time and accuracy. After consulting with David Leversage the decision was revised and an IC sensor was selected. This decision was based on the simplicity of the circuit that would need to be created and also due to BCIT having many of the components required for the circuitry.

3.3.3 Selection and Implementation

The IC sensor we selected is the LM335Z. This sensor has a slow response time relative to other types of sensors, but the less than four second response time in a stirred oil bath indicated on the datasheet (appendix A) is more than adequate. This sensor also boasts accuracy much greater than the ± 3ºC that is required to receive maximum points in the competition.

With the help of David Leversage (Leversage, 2008) an initial electrical circuit was designed. Upon further inspection of the microcontroller selected by the controls team, it was determined that the amplification circuitry was not necessary. After finalizing the temperature sensor circuit design (appendix A), Chris Zeng (Frame & Controls Group) and Paul Wytenbroek manufactured the printed circuit board. Then the electrical components were soldered onto the circuit board and waterproof silicone sealant was applied to all of the exposed contacts. The circuit board will be mounted inside of a PVC pipe with a removable end cap to allow access to the potentiometer (for calibrating the sensor). The sensor end of the circuit board will protrude from the pipe and will be sealed in place. To minimize the buoyant force produce by the sensor assembly, the housing will be sized such that its displacement is minimized. The waterproof sensor assembly will then be attached to the flow diversion device that is in turn mounted on the ROV.

An appropriate length of wire will be attached to the circuit board and passed through the screw-in end cap on the back of the sensor housing. The removable end cap will have a rubber o-ring to prevent water from entering the sensor housing. The positive, negative, and signal wires will be connected to the microcontroller so that the temperature reading can be relayed to the surface display screen.

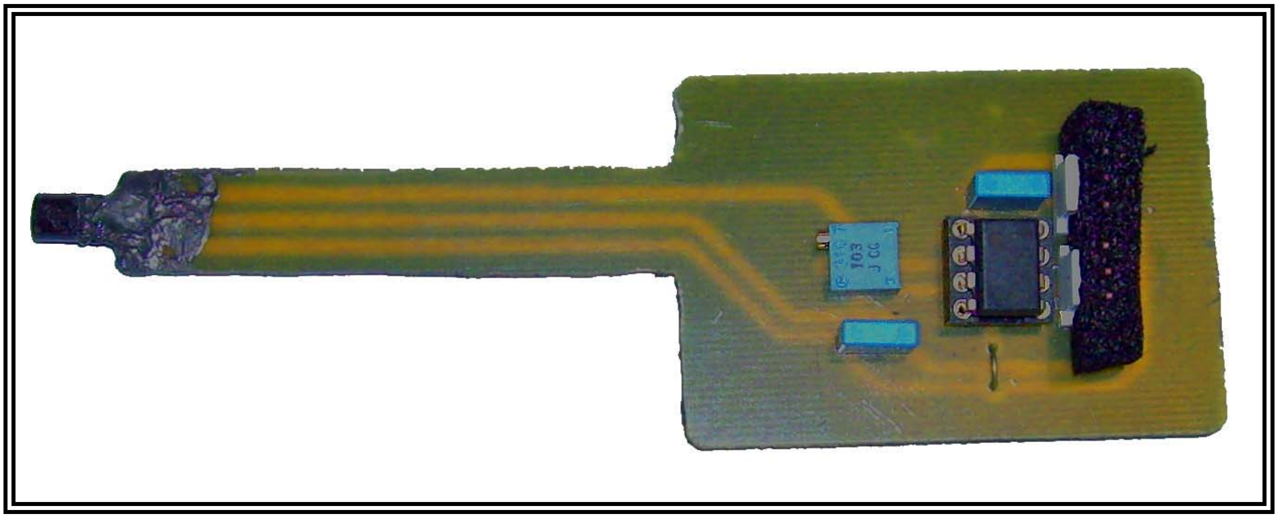


Figure 33: IC Temperature Sensor

Figure 33 shows the circuitry for the IC temperature sensor. Located at the far left is the sensor itself, about 1/8: in diameter.

3.4 Flow Diversion Device (FDD)

The flow diversion device is used to direct flow from the hydrothermal vent past the temperature sensor. The hydro thermal vent stands approximately 2 ft high and is 3 inches in diameter, with a ½ in hole off center in the top where the fluid flows from. The purpose of the FDD is to sit over top of the hydrothermal vent, redirecting the fluid from the vent past the temperature sensor as well as blocking out the pool water that may cause an inaccurate reading. The FDD is made of PVC sheets that were cut and shaped into a funnel, then were reinforced with a fiberglass shell. A slot will be made in the last sections of the FDD allowing the temperature sensor probe to be placed in the flow, while also securing the temperature sensor circuitry to the FDD. Below is a picture of the as built flow diversion device to be used to direct the vent flow.