

POLAR SUBMERSIBLES

University of Alaska Fairbanks

Ironsides



Team members:

Vincent L. Weibel, Kluane Dominique
Weibel, James Halliday, Logan
Hanneman

Mentor:

Orion Lawlor, Katherine Weibel

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The Team

Vincent L. Weibel



Vincent is in charge of the propulsion and robotic arm. He also is the primary pilot.

Kluane D. Weibel



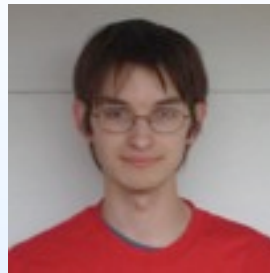
Kluane helps with all of the systems on the ROV. She has done everything from building the thermistors to fabricating the basket. She is also the primary tether manager.

Logan Hanneman



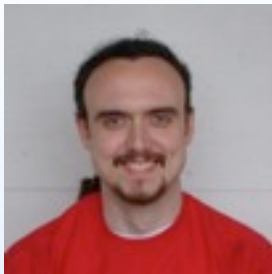
It is Logan's second year on the team. He helps with all aspects of the construction and design, especially heavy metal construction.

James Halliday



James worked on the programming and electronics for the ROV. James also helped with some of the basic construction. This is James' first year on the team.

Orion Lawlor



Orion is a Computer Science professor at UAF, and is the team's mentor. He advises as well as supplies his tools. Orion also acquired many of the parts used on the ROV.

Abstract

Our 2008 ROV is designed to be simple, durable and low maintenance. The 2008 International MATE ROV competition will be Polar Submersibles third year. To minimize cost, to limit complexity, and to better understand how the ROV functions, Polar Submersibles custom built many components from salvaged parts and scrap materials. By going green the team utilized items that would have otherwise been thrown away.

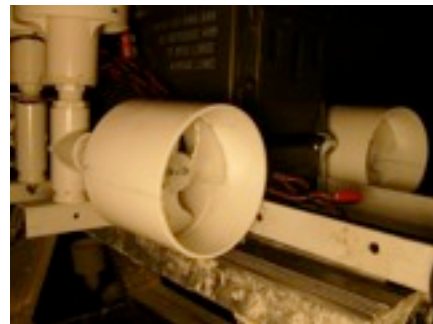
The ROV has eight thrusters: four vertical and four horizontal. The thrusters and robotic arm are controlled by an onboard microprocessor which is in turn driven by serial commands sent from topside via a cat-5 cable. The topside controller is a USB game pad that connects to a computer wired to the tether. Video is transmitted through the cat-5 for multiple cameras that can be switched topside. Power to the ROV is provided alongside the cat-5 on 10 gage wire. A robotic arm and temperature sensor were added to help complete the missions.

Design Rationale

Propulsion

This year's competition requires heavy lifting, therefore our ROV has eight thrusters: four vertical for maximum thrust in ascending and descending. Four horizontal thrusters are arranged for forward and reverse which lends to skid steering. The four horizontal thrusters are also rotated inward to provide horizontal translation.

The thrusters are constructed from 1250 Attwood bilge pumps. We found that constructing our own thrusters was cheaper but a great challenge. Our team reconfigured regular bilge pumps by stripping the outer housings away from the sealed motors and attaching propeller blades. The propellers were constructed from salvaged sheet aluminum which were modeled after an office fan blade.



Mission Tools



Our ROV has an all-steel robotic arm. It is comprised of two high torque geared DC motors. One motor is connected through a series of levers to a pair of needle nose pliers allowing for exceptional gripping power; while the other motor is devoted to raising and lowering the arm. All other motions required to manipulate the arm are performed by the movement of the ROV itself, simplifying the amount of motors needed on the robotic arm to complete a mission.

For the temperature mission, the team built an electronic probe that displays the temperature on the computer screen. The thermistor, located on the tip of the probe, is a resistor that varies its resistance with temperature. We use a voltage divider to convert the resistance into a voltage that can be input into an Analog-to-Digital PIC port. We used a Zener diode to regulate the voltage. The computer takes averages of the fluctuating temperatures in order to achieve a more accurate reading. The thermistor probe is placed at the top of a funneling device which will help to place the temperature probe above the hydrothermal vent. A dedicated PIC was placed near the thermistor, to reduce noise from the motors, cameras and other sources of electrical noise.



Thermistor printed circuit board

To collect the three bean bags, our robotic arm has the ability to place bags into a mesh and wire basket to haul the load to the surface. In order to prevent the weights from shifting the ROV's center of mass a hook is mounted directly under the ROV to pick up the basket.



Main Fuselage/ Frame

The ROV is constructed from repurposed angled steel bed frame appropriated from a waste transfer site. It was cut and welded together to support a used 40 mm military ammunition box. The ammunition box was chosen because it is inexpensive, robust and provides an air tight quick accessible compartment. The steel frame provides a solid mounting surface and overall rigidity. The location and the mass of the steel help stabilize the ROV. Salvaged rollerblade wheels were attached to the frame to transport the ROV.

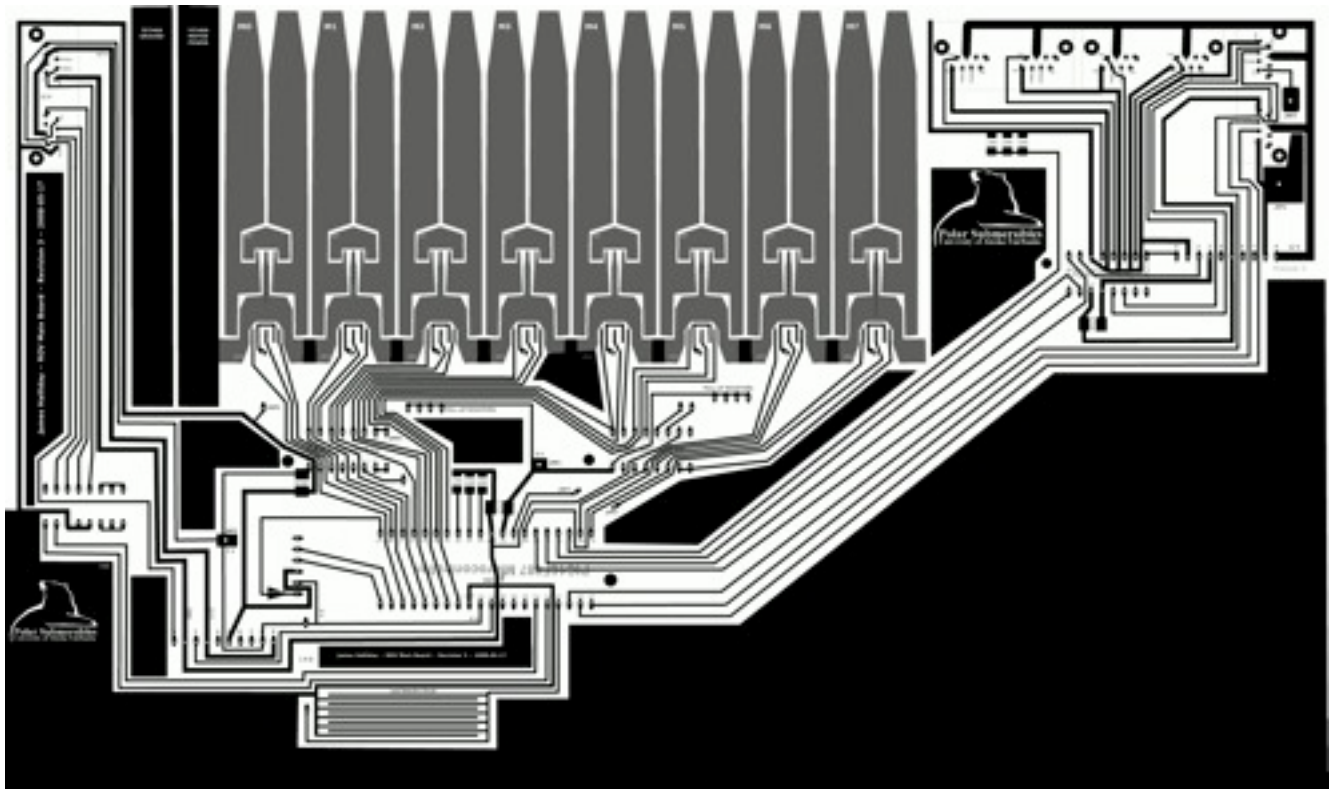
Electronics / Video

Our electronics board is built from scratch using the toner transfer iron-on technique. Eight h-bridges control the motors and robotic arm. Video is also tired into the electronics board. The main board consists of a single printed circuit that protrudes from the lid of the ammunition canister. Video is generated through camera pods that can be placed anywhere on the ROV. The video pods have inexpensive cameras sealed inside. All video is viewed on the top-side control computer.

Components

A PIC 16F887 microprocessor was chosen to control the thrusters, arm, and cameras on the ROV because it has enough pins to perform all of these tasks on a single chip and also has hardware serial functionality for communicating with top-side.

The PIC 16F887 drives eight h-bridges that switch high current power from the tether for running the motors in forward and reverse. We chose ST Micro VNH3SP30TR chips, which are just \$7.50 and switch up to 30-amps. They are surface mounted chips which were soldered at UAF's hot air rework station. Two h-bridges drive all four of the vertical thrusters, but the other motors have their own h-bridges.



ROV printed circuit board

Two inverters were used to simplify the software and lower the number of pins required to drive all 8 h-bridges. Each motor requires only 2 pins from the PIC 16F887 as opposed to 3 to run in both directions. The PIC also required an inverted serial transmit line with respect to the top-side equipment.

A DG408D video multiplexer chip was selected to avoid annoying crosstalk involved in sending multiple video signals down the tether. The chip supports up to eight video signals, and so room was wired into the PCB for six cameras. With this chip and technique, only one line for video data is needed for all six cameras.

The temperature sensor has its own PIC 12F675. This PIC model is capable of measuring voltage off the thermistor circuit to obtain digital temperature information.

Top-Side perl Control Module

```
# ROV control module
package ROV;
our $VERSION = 0.01;
use 5.10.0;

use Carp;
use strict;
use warnings;

sub new {
    my $class = shift;
    my %args = @_;
    $args{dev} // croak "Required parameter 'dev' not provided";

    open my $fh, "+<", $args{dev} or croak "$args{dev}: $!";

    use IO::Select;
    my $select = IO::Select->new;
    $select->add($fh);

    my $self = {
        dev => $args{dev},
        fh => $fh,
        select => $select,
        commands => {
            motors => chr 0x71,
            leds => chr 0x72,
        },
        replies => {
            cmd_ok => chr 0x81,
            unrecognized => chr 0x82,
            data_ok => chr 0x83,
        },
        level => 1,
        max_level => 128,
        min_level => 1,
        timeout => $args{timeout} // 0.1,
    };
    $self = bless $self, $class;

    # Discard the bytes coming off the line, probably from noise
    $self->wait_reply;

    sleep 1;

    # Power down the motors and leds
    $self->set_motors;
    $self->set_leds;

    return $self;
}

sub DESTROY {
    my $self = shift;
    # Turn off the motors and leds before closing the handle
    $self->set_motors;
    $self->set_leds;
    close $self->{fh};
}
```



```

sub set_level {
  my $self = shift;
  $self->{level} = shift;
  $self->{level} <= $self->{max_level} or $self->{level} = $self->{max_level};
  $self->{level} >= $self->{min_level} or $self->{level} = $self->{min_level};
  $self->send_motors;
}

sub set_motors {
  my $self = shift;

  $self->{motors} = [ (0) x 8 ];
  for my $r (@_) {
    $self->{motors}[ $r->[0] ] = $r->[1];
  }
  $self->send_motors;
}

sub send_motors {
  my $self = shift;
  # Send the command and data until both are acknowledged
  my $tries = 0;
  do {
    # Send command until a CMD_OK is received
    do {
      $self->send_cmd($self->{commands}{motors});
      $tries ++;
      $tries < 10 or croak "Too many retries";
    } until $self->wait_reply eq $self->{replies}{cmd_ok};
    $self->send_data($self->get_motor_data);
  } until $self->wait_reply eq $self->{replies}{data_ok};
}

sub get_motor_data {
  my $self = shift;
  return join "", map {
    chr +($_ > 0) * 128 + ($self->{level} - 1) * abs
  } @{$self->{motors} };
}

sub flip_leds {
  my $self = shift;
  for my $n (@_) {
    $self->{leds}[$n] ^= 1;
  }
  $self->send_leds;
}

sub set_leds {
  my $self = shift;
  $self->{leds} = [ (1) x 3 ];
  for my $r (@_) {
    $self->{leds}[ $r->[0] ] = 1 - $r->[1];
  }
  $self->send_leds;
}

sub send_leds {
  my $self = shift;
  # Send the command and data until both are acknowledged
  do {
    # Send command until a CMD_OK is received
    do {
      $self->send_cmd($self->{commands}{leds});
    } until $self->wait_reply eq $self->{replies}{cmd_ok};
  }
}

```

```

        $self->send_data($self->get_led_data);
    } until $self->wait_reply eq $self->{replies}{data_ok};
}

sub get_led_data {
    my $self = shift;
    return chr (
        + ($self->{leds}[0] << 0)
        + ($self->{leds}[1] << 1)
        + ($self->{leds}[2] << 2)
    );
}

sub send_cmd {
    my $self = shift;
    my $cmd = shift;
    printf "SEND CMD: %02x\r\n", ord $cmd;
    syswrite $self->{fh}, $cmd;
}

sub send_data {
    my $self = shift;
    my $data = shift;
    print "SEND DATA: ";
    printf "%02x ", ord for split //, $data;
    print " (" , length $data, ")\r\n";
    syswrite $self->{fh}, $data;
}

sub wait_reply {
    my $self = shift;
    my @ready = $self->{select}->can_read( $self->{timeout} );
    @ready == 1 or return chr 0; # timed out

    my $len = sysread $self->{fh}, my $reply, 1024;
    $len > 0 or croak "Broken pipe";

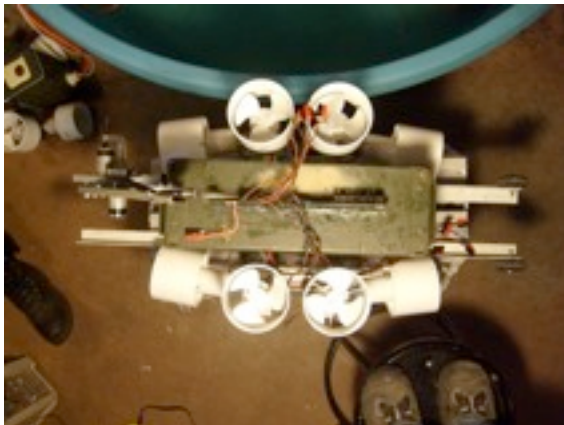
    # Take the last byte on the line
    $reply = substr $reply, $len - 1, 1;

    printf "REPLY: %02x\r\n", ord $reply, ord $reply;
    return $reply;
}

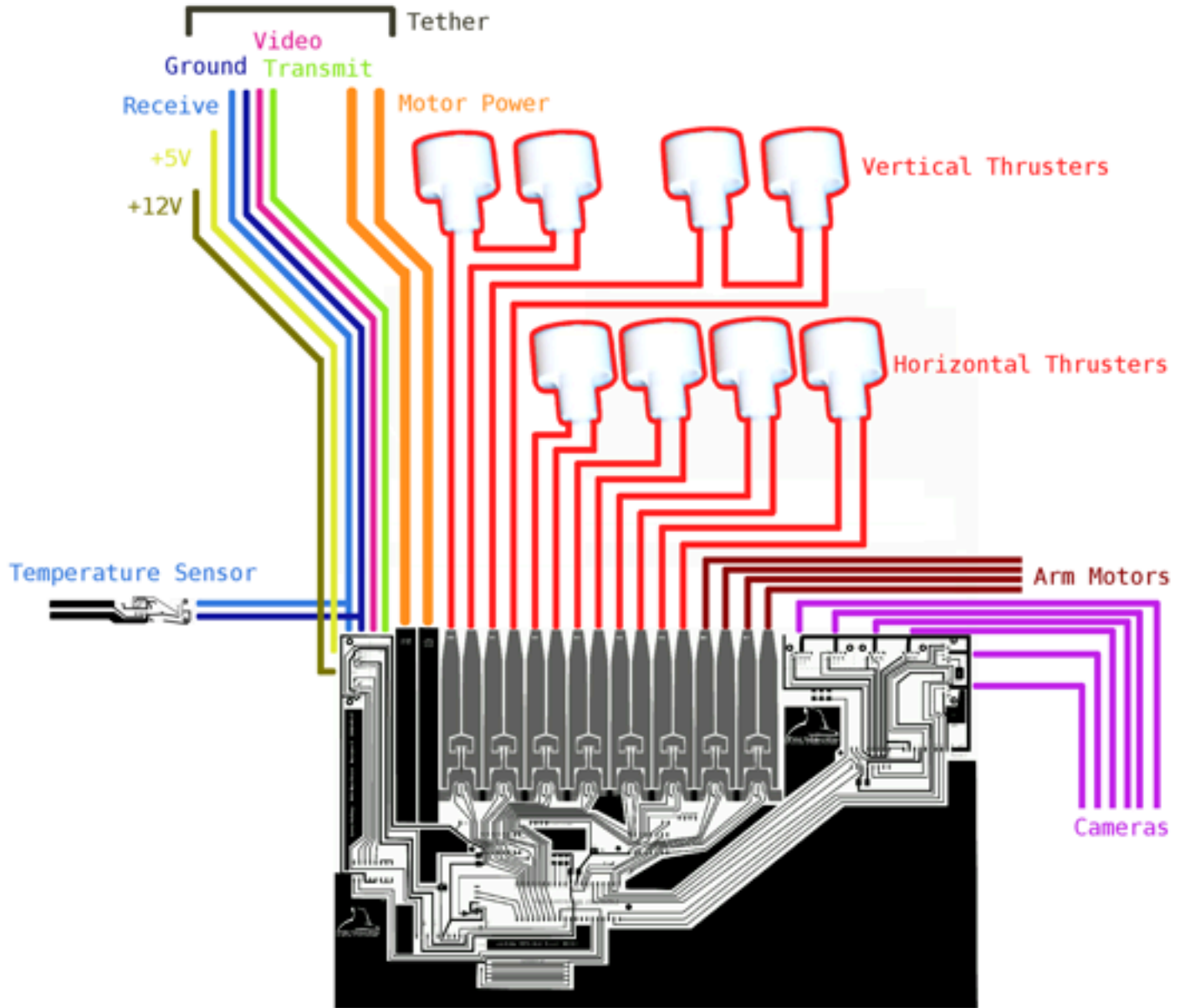
1;

```

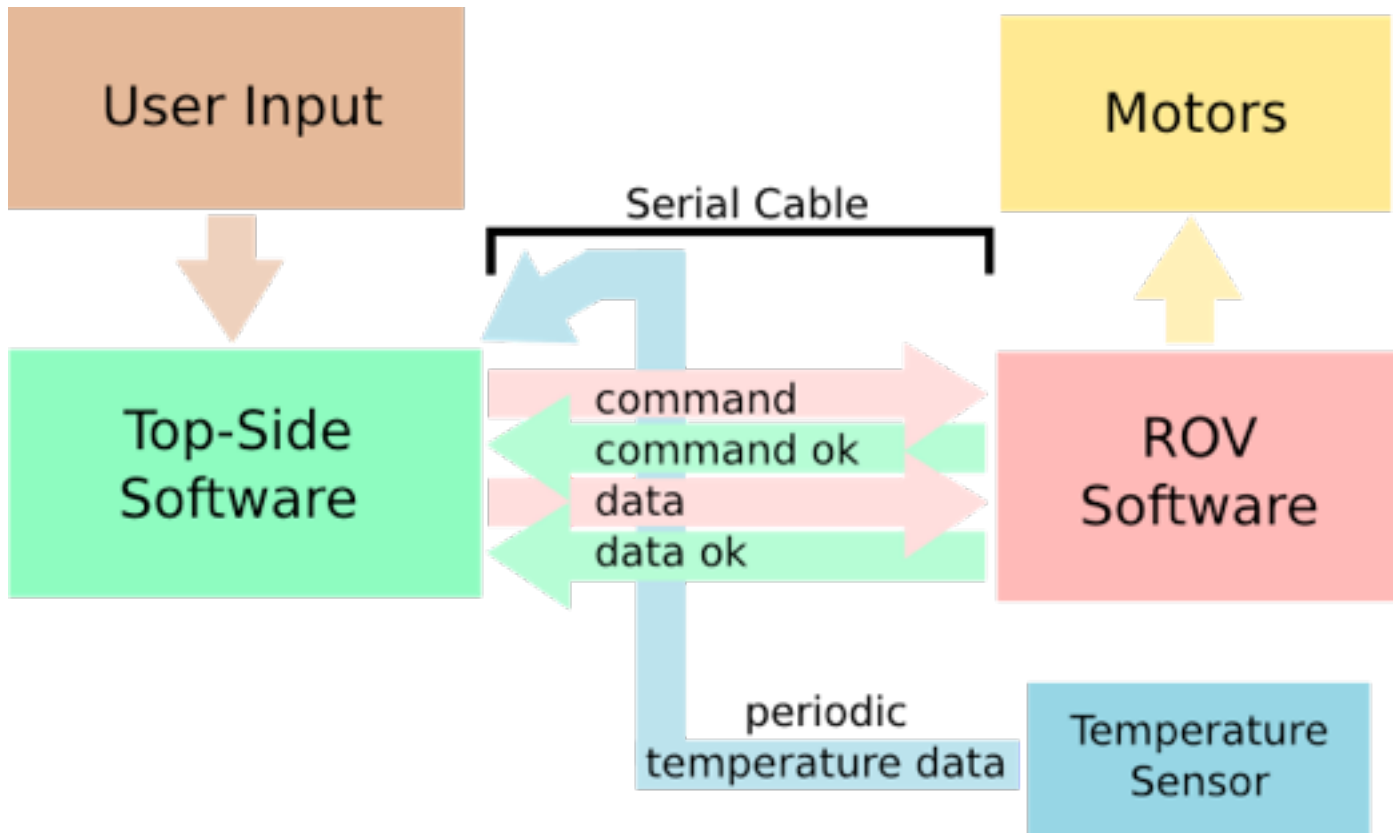
Pictures of ROV “Ironsides”



ROV Electrical Design



Block Diagram



Challenge

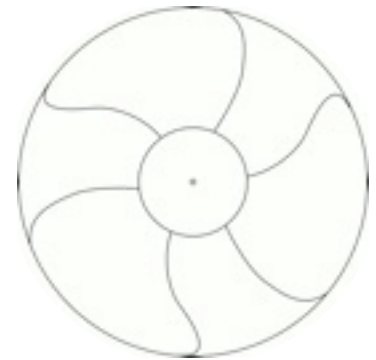
Our team was very pleased with our thrusters from 2007. They were inexpensive and small in size. Polar Submersibles decided to use the same design for the 2008 ROV. The 2007 blades came from office fans purchased at a local hardware store. However, the store no longer carries the fans, so when our team tried to buy the fans directly from the company, the cost to ship to Alaska would have been prohibitive. Our team was faced with a challenge of finding another fan blade or building one from scratch. After searching all the stores in the area and browsing the internet, no fan blades proved satisfactory. Our team agreed to build the fan blades ourselves from plastic.



Creating a blade turned out to be more difficult than planned. First we bought some plastic Lexan of different thicknesses and cut out discs. From the discs we tried different numbers of blades: two all the way up to five. We cut slots in the sides of the discs and used a heat gun to bend the blades to our desired shape. To test the thrust of the blades we wired an old thruster from last year and a new thruster together on opposite ends of a pole. The pole allowed us to easily measure which thruster was stronger. The plastic disc blades that we fabricated did not provide as much thrust as our blades from 2007. Our team decided to make a plaster mold of an older blade and attempted to drape the discs over the mold with the application of a heat gun. This approach

did not work, even though the look of the blade was closer to the original office fan blades.

Our team realized we needed a thinner and stronger material, serendipitously we recently received some used aluminum door kick-panels. The thickness of the aluminum was perfect and the metal was easy to bend. Cutting the exact shape of a blade proved difficult. However, we created a printout of the blade shape that was glued to the aluminum surface. Applying the printout allowed the blade shape to be easily cut out of the metal. After the cutting was completed all that remained was to bend the blade at an efficient angle that would allow for better thrust. The first prototype had the same angle as the original prop blade, however it did not provide the same thrust output. We tested varying angles from almost zero to 45 degrees. Our team decided we wanted a reversible blade and noticed that the original blades worked better in one direction than the other, due to cupped blades. To keep the design simple, Polar Submersibles decided to leave out the cupped blade. A flat blade provides equal thrust when spinning in either direction. The new blades, with an acute angle, produced the same thrust as the originals. Our team was able to create a better thruster blade that is cheaply reproduced. The learning experience, customizability and cost savings associated with manufacturing our own thrusters was worth the temporary struggles.



Propeller template

Troubleshooting Techniques

A problem before the first water test arose with serial-communications. The thrusters would intermittently fail to spin when instructed, and the problem seemed to get markedly worse when the full-length tether was attached. A number of tests were devised to test serial data. First, the tests centered around the ability to receive communications from the ROV. Strings of increasing multiples of 0x11 were sent down the line and printed out in hexadecimal on the top-side computer. These strings were received properly top-side. To check whether the ROV was receiving properly, since the ROV proved capable of sending data to top-side, a simple program was written for the ROV's main microprocessor that only relayed back exactly the data it received from top-side. This test, like the motors, would only occasionally succeed. The tether was tested for breaks, but none were found. Finally, we discovered that a surface-mount capacitor that the design called for between +5V and ground on the left inverter hadn't yet been soldered down. The top-side was able to receive communication from the ROV because that receive line did not go through an inverter, but because the transmit line required inversion, it was not functioning reliably. After a quick solder job to add the missing component, the robot fired its motors properly and was able to cruise around in the water.

To measure the amount of thrust our motors produced underwater, we attached counter weights to the motors. The motors were submerged in water and increments of weight were added until the motors could barely lift the weight.

The arm required several rebuilds due to inefficient material strength. The first arm was built with thick polyethylene plastic, the plastic stripped out and proved weak. The next model used thin metal tubing about 2 mm thick. The tubing was strong for a while, but fatigued after repeated testing. The final design incorporated the metal tubing and 1.25 cm thick hot-rolled iron bar attached to the motor's shaft as a mounting block. The final robotic arm is strong enough to survive long term use.

Future Improvements

Our team designed the main housing to accept two 26 amp hour batteries. Having two batteries on board would decrease the need for such a large tether. The batteries would also serve as ballast and we would not suffer voltage drop going across the tether.

We plan to improve the robotic arm by incorporating interchangeable pinchers for adapting to different mission tasks. An arm with increased flexibility would allow the team to perform more complex tasks. Upgrading the motors to worm-gear motors, for the robotic arm, would keep the arm locked in position when voltage was not applied.

A DC to DC converter will be installed in next year's ROV, provided we do not use onboard batteries. This way high voltage can be sent down the tether and converted to 12 volts. 12 volt motors, lights and cameras are more readily available than 24 or 48 volt components.

It was hard to make the aesthetic look of the ROV appealing this year because a majority of the components were salvaged from refuse piles. Our team takes pride in the craftsmanship of our ROV and would like to improve its appeal. Additional paneling, form-fitting ballast and buoyancy would improve both hydrodynamics and appearance.

Lessons learned / Skills gained

A number of printed circuit boards were required for the ROV. We chose the toner transfer iron-on technique to fabricate the boards for this project because the technique is low cost, it uses easily obtainable equipment, and has a quick turnaround time. We designed the board diagrams with the free software vector graphics program, Inkscape, and printed these designs onto glossy magazine paper with a laser printer.

An electric iron was used to fuse the paper with toner onto the copper side of a sheet of copper-clad FR-4 fiberglass. After fusing, the board and paper were immersed in water for a few minutes to weaken the paper. The paper was gently rubbed away while the toner remained stuck to the copper. The sheet was then immersed in a bath of muriatic acid and hydrogen peroxide and churned until the acid had dissolved away the areas of copper not covered in toner. The sheet was then removed from the bath and rinsed with water. After this process, the boards were ready for components

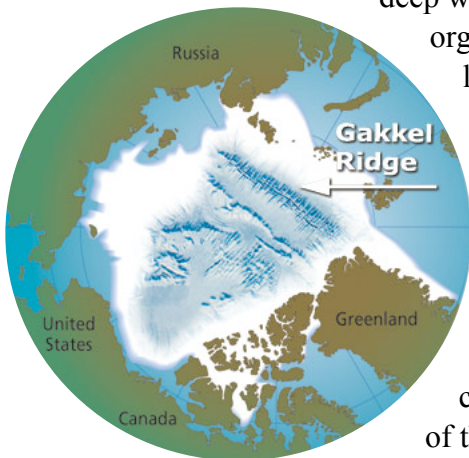
Our Team learned that capacitors are a necessary component to the electronics board. On the electronics board we mounted a 10 volt rated capacitor, but our voltage was 12 volts. Our safety 25 amp breaker was very useful for stopping the surge, but we popped the capacitor and realized our mistake. The correct capacitor is necessary for keeping the voltage regulated. Our team soldered on a new capacitor and attached a diode for possible future complications. The advantage of the popped capacitor was that it gave us an excuse to dissect and unroll an electrolytic capacitor.

Scientist/Research project



In July of 2007 the Woods Hole Oceanographic Institution began an expedition to the arctic, during the International Polar Year. A team of scientists explored the unknown depths of the Gakkel Ridge using autonomous underwater vehicles named Puma and Jaguar. Also a Conductivity/Temperature/Depth sensor, CTD, and a tethered video and sampling device were used in the exploration. The objective was to find and understand how arctic hydrothermal vents operate and what type of life exists.

Mid-ocean ridges are the longest chains of volcanoes on the Earth; they stretch about 60,000 km. They are a spreading boundary, separating the tectonic plates. At these spreading centers, magma erupts to form new crust. Hydrothermal vents are found along these spreading ridges. They are formed from super heated sea water, which collects minerals along the way, then spews out from the cracks in the ridge. Organisms are usually found on and around the vents. Each hydrothermal vent cluster is like an island supporting different forms of life. The vents support life via chemosynthesis through the precipitation of sulfides. Life would have begun in a minimal to zero oxygen environment; therefore hydrothermal vents are a glimpse into the early life cycle.



The Gakkel Ridge is located in the arctic ocean and is about 1,800 kilometers long. It has been a closed deep water basin for about 28 million years and isolated from the rest of the benthic organisms. The Gakkel Ridge is a very slow moving ridge, which means there is low volcanic activity, but there are still hydrothermal vents. Therefore the gases and minerals, which the benthic organisms are consuming, will be different from those found along a ridge with volcanic and hydrothermal vent activity. So the theory is that different organisms, similar to early life, will be discovered around the vents. Large amounts of ore deposits were found which are an indication of hydrothermal vents.

The ROV recorded amazing video of life in the arctic mid-oceanic ridge and mapped the bathymetry of the ridge. The CDT was able to indicate changes in the water chemistry and temperature. The temperature and clarity of the water is an indication of hydrothermal vents, normal sea water is cold and clear, whereas water that is warm and teeming with minerals is likely coming from a vent. The tethered vehicle, meant to bring back biological and geological samples, was able to record video and collect geological samples of the ridge. Although no vents were sighted, a cirrate (winged octopus) was seen. The octopus lives in deep water and eats crustaceans, shrimp and crabs, which could be an indicator of vent life somewhere on the ridge.

The mission was a great start in the discovery of arctic deep sea vents. Although no vents were sighted the team of scientists found other forms of life and recovered samples of rock. The information gained from exploring the arctic vents will greatly aid in the future exploration to Europa by NASA. Mankind has always searched to understand what it doesn't see or know; underwater vehicles make exploring the ocean bottom possible. From the extraordinary video and sampling, teams of scientists are now able to understand the ocean environment.



Expense Sheet

ITEMS	UNIT COST	ROV COST	TOTAL PROJECT EXPENSES
Thruster	\$35	\$276 for 8	\$700
Cameras	\$14	\$56 for 4	\$140
Electronics board			\$70
Main housing	\$3	\$3	\$6
Chassis			Free steel from dump
Tether 10 AWG wire and cat-5			reused from last year
robotic arm motors	\$7.50	\$15	\$15
robotic arm parts			Free steel from dump
thermistor	\$0.10	\$0.20	\$0.20
Plane tickets (5)	\$450		\$2,250
TOTAL			\$3,181.20

Resources

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Dave Christie from the West Coast and Polar Regions Undersea Research Center for inspecting our ROV for MATE.

MATE for organizing the 2008 ROV competitions, for which we will share our experiences and knowledge with young students attending Alaska's Summer Research Academy (ASRA, organized by Jeff Drake of the University of Alaska Fairbanks and Ed Moriarty of the Massachusetts Institute of Technology).

Our mentor Orion Lawlor for all his help and advice.

All our parents, friends and family for their encouragement, support and contributions.

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