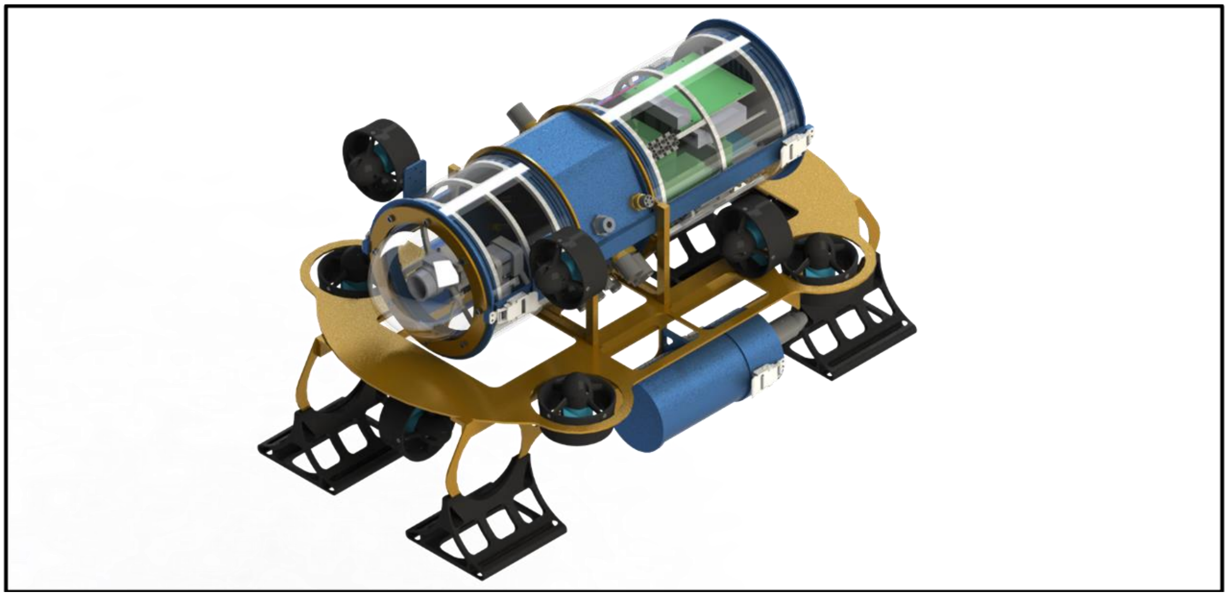
Falcon Robotics AUV Team
Project Sovereign Falcon 3.0



Abstract:
This is Falcon Robotics AUV Team's fifth year of participation in the Robosub competition. Our plan of building an AUV platform that we can expand on year after year was abandoned this year. It became apparent that in order to be a top team we would need to incorporate a robust navigation system. The AUV must "know" where it is in the water at all times. We decided that we needed a DVL and a hyper accurate Fiber Optic Gyro. So we designed a new AUV based on our four years of experience in order to get us to that top three category. Another new innovation came in the form of new thrusters from Blue Robotics. They are 1/6th the cost of the AUV thrusters used by most teams. The construction of a new AUV with these new components and the expertise needed to integrate them will make this a two year endeavor. This year will be step one, in which the main focus will be basic control systems and preliminary vision processing and rudimentary navigation. The next year will be step two with the completed AUV with a robust navigation and vision system. If events unfold as we are planning, we will have a exceptional AUV that could vie for the victory in the 2016 AUVSI & ONR Robosub competition.

Dry Weight: 20Kg(?) **Dimensions: 81.28cm x 55.88 cm x 40.64 cm** **Max Speed: 12m/s** **Max Depth: 12 meters** **Thrusters: 10 Blue Robotics T-100, Kgf, 11.0 Amps**	**Cameras: USB 1080p board camera** **Nav: KVH FOG, Teledyne Explorer DVL, TRAX.** **CPUs: -Intel i7 4.0GHz, 64 bit, Linux** **Innerloop: ARM Cortex M4, 96MHz, 32 bit**

Team background:

Located in central Phoenix, Arizona, Carl Hayden High School is an inner city school with many common inner city challenges. Some characteristics that further distinguish

Hayden include, 98% of the student's population qualify for the federally assisted school lunch program, 97% are Hispanic, and an overwhelming majority are first generation immigrants. Many of these students are also the first in their family to graduate high school.

In 2001, Allen Cameron and Faridodin "Fredi" Lajvardi formed the Falcon Robotics team. The club came together initially to show students that science and technology could be interesting and fun but it rapidly evolved into something far more powerful. Now the team is a school within a school or a "robotics academy" of sorts. An average of 3 hours a day are spent by students and mentors designing and constructing robots to compete in various competitions year round. The competitive spirit, a sense of social responsibility, along with the natural aversion to embarrassment drives the learning experience. The program continues to thrive!

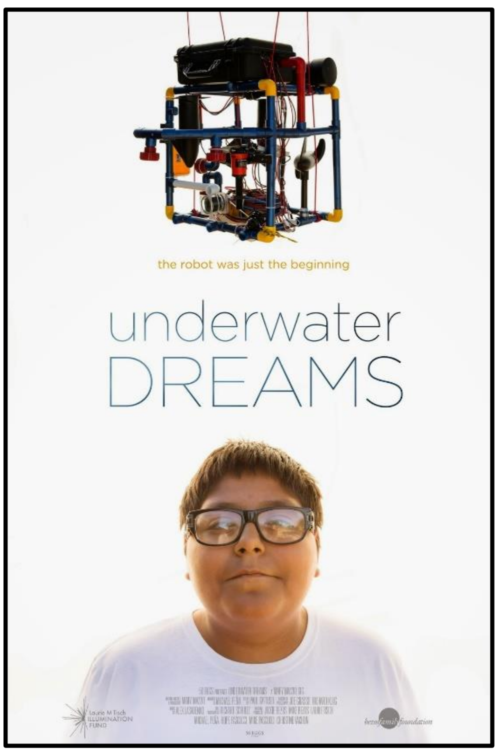
Team outreach:

The falcon Robotics team has many outreach activities. From holding Lego robotics competitions for grade schoolers and science and technology fairs for the public, the team has been very instrumental in affecting STEM education in Arizona.

The past year has been an extremely busy year for public outreach. In January our team was very lucky in having our story shown on the silver screen. The movie, Spare Parts, tells the story of four former Carl Hayden students competing in a MATE National Underwater Robotics Championships. The four team members had nearly all the odds stacked against them. With a very low budget of just $800, they managed to build an underwater robot. The team entered the college level of the competition and won the entire event! They won against universities such as Virginia Tech and the Massachusetts Institute of Technology. Spare Parts was Hollywood's twist of the story featuring actors like George Lopez, Jamie Lee Curtis, and Marisa Tomei.

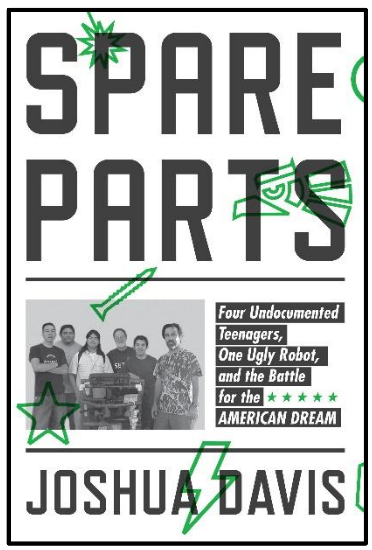
After a very special premiere at Carl Hayden High school, the movie was released across the country. Many people across the nation were able to enjoy this motivational film. Months later the movie was released in Mexico. Today, the story is now available on DVD. What makes this movie have a direct connection to the current team is that all the remotely operated vehicles in the film were built and operated by the current Falcon Robotics team members. The film was even shown at this year's Sea Perch Competition, thus demonstrating the impact the Falcon Robotics Team has not only in Arizona, but across the country.

As if that wasn't enough, there is also a documentary that was released right after the Robosub competition last year. Underwater DREAMS has been receiving wide acclaim across the whole country. The documentary tells the story of how four young Hispanic students from the mean streets of Phoenix got together with two innovative teachers to form a team that would



change the stereotypes of young Hispanic youths and what effect their accomplishments have had on the school, community, state and the country. Many groups and organizations across the country have been screening the film followed by a panel discussion including at the White House by the Office of Science and Technology. The film is now part of President Obama's new STEM outreach initiative and sponsors have made the film available to everyone who wants to stream it through their promotional website. (http://www.epixhd.com/movie/underwater-dreams/) The original team members and the two teachers have been traveling around the country telling their story of how talent in the United States can come from some of the most unlikely places.

Wait, there is one more piece of evidence that the Falcon Robotics Team can list as outreach!



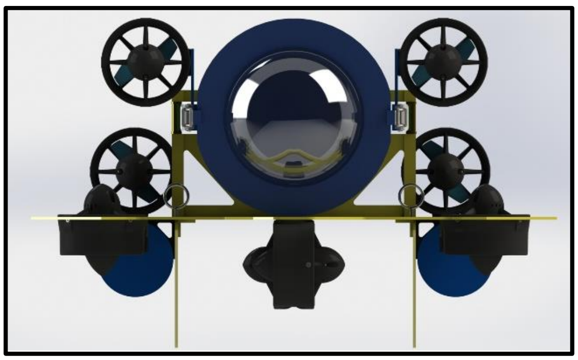
There a book called, Spare Parts: Four Undocumented Teenagers, One Ugly Robot, and the Battle for the American Dream, written by Joshua Davis. The book chronicles the story of how the Falcon Robotics Team beat MIT in an underwater robotics competition. So as you can see, the Falcon Robotics Team has definitely made an impact out in the world.

Robosub Team Collaboration:

The Falcon Robotics AUV team has been collaborating with The University of Arizona AUV Team on technical issues concerning the AUVs. We have also pooled our resources so that sponsors will be able to sponsor two teams with one set of components that we both would then share. Our collaboration has yielded some very exciting results. We were able to secure funding for a $17,000.00 Doppler Velocity Log and other components as well that are under development and will take at least another year to reach full fruition and we hope to be two of the top teams in Robosub 2016.

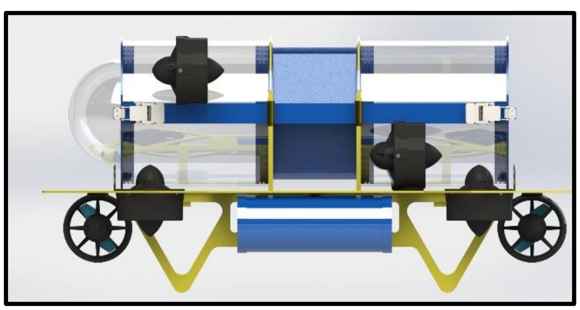
AUV construction:

Our AUV was designed to be light weight and strong simultaneously. We designed the AUV using Solidworks. Most of the AUV frame was cut out using water jet. The main part of the frame consists of one

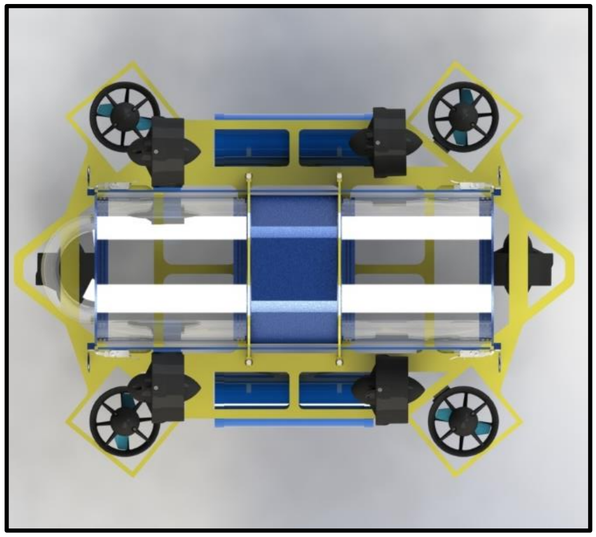


large plate ⅛" thick with two side legs for support. The legs are attached the main part of the frame with 1/16" aluminum angle to support the base and make it elevated for components to be placed at the underneath.

There are ten thrusters total. Four are mounted in each corner to move the AUV up



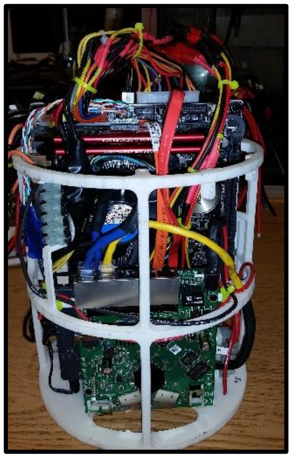
and down in the vertical position which are bolted to the frame with 1/8 in. thick square tubing. There are four more thrusters in the horizontal direction to move the AUV forwards, backwards. These are mounted two on each side of the main hull and bolted to the frame using 3-D printed mounts. There are two additional thrusters at the bottom of the



AUV on the front and back to rotate the AUV left and right.

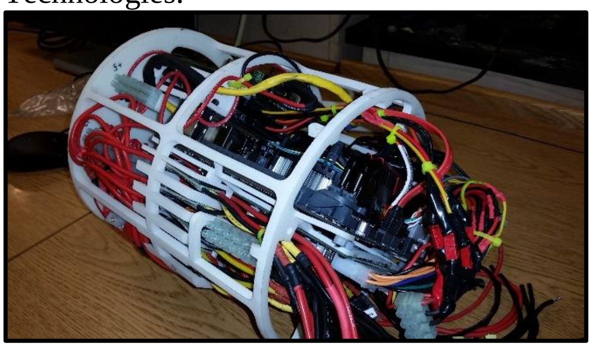
The AUV has two battery compartments on the sides of the robot. The battery compartments are made out of 3" diameter polycarbonate tubing. The battery compartments will have a lattice structure to keep the batteries from moving around

3D Printed parts:



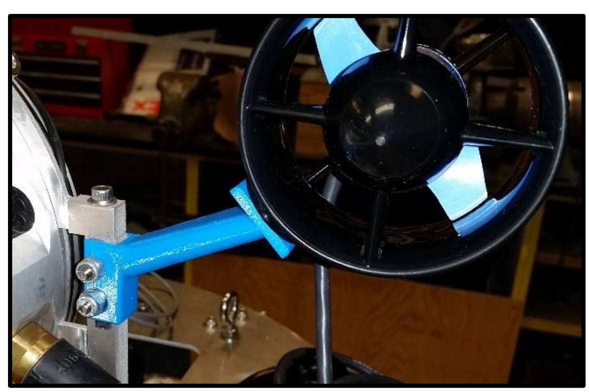
We utilized our sponsorship of a 3-D printing company and our own Makerbot to its full capacity with this year's AUVSI robot by printing key components that that would otherwise be difficult to obtain by cutting and welding the item.

The most important, and absolutely necessary, part printed for the robot is the electronics lattice. It is what holds many of the electrical components as well as the computer; basically, the “skull” of the robot, which holds the “brain”. This task, if done by using metals, or even wood, would be extremely difficult considering our situation. Nearly impossible, if not using a mold, to accomplish since our needs were very specific and we have very little space to spare inside the hull. The electronics lattice was printed for us by Phoenix Analysis Design & Technologies.



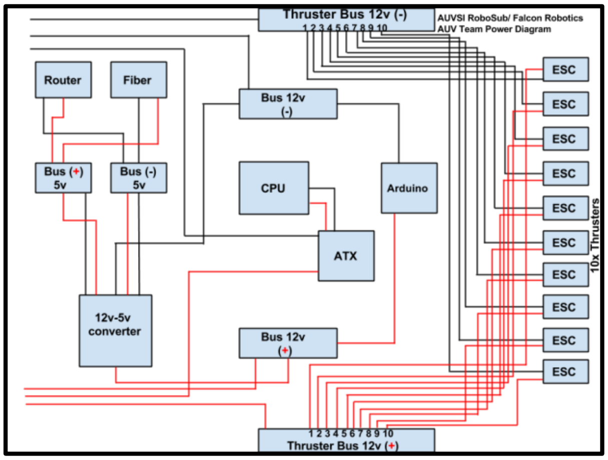
The second crucial parts printed with our own 3-D printer, were the nuts that hold our Subconn connectors on to the hull. Due to the hull being too thin in some places to have threads in, it was decided that we would have to use nuts instead. This would present us with a new problem. The hull being round on the inside with six flat surfaces on the outside, we had to solve the problem that traditional nuts have, being flat on both sides. Eliazar Diaz, a fellow team member, came up with the idea of printing a custom nut with a flat and curved side with PLA filament. The durability and sturdiness of the PLA filament, printed at 100% fill, made it perfect for this project because it satisfied the requirements to solve the issue. The price per roll of filament added to the pros of using this custom nut for our robot, this also allows us to print many nuts and nuts linked together to form wedges which we called our Subconn Wedges.

The third necessary parts we printed were the thruster mounts. We had four thrusters that needed custom mounts this year, and with limited time and unlimited creativity and some PLA filament, Raymundo Nevarez was able to design a supporting piece for two thrusters to be bolted onto a vertical frame holding the hull in place mirrored on the opposing side and

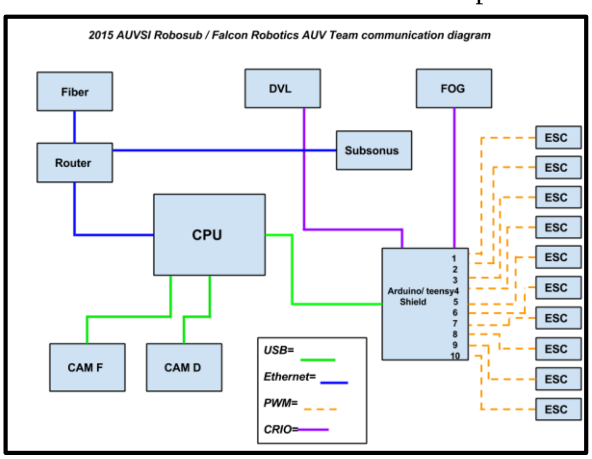


two more on a horizontal surface of the main frame near the rear of the robot. Designing the mount and printing it ourselves granted us the freedom of adding custom surfaces to the mount easily, mostly for increased hydrodynamics.

Electrical:



The AUV is powered by two 14.1v, 10 amp/hour lithium polymer batteries, with one battery on each side of the AUV in a self-contained compartment. This will result in a power pack that is 14.1 volts with a 20 amp/hour capacity. Each of the two compartments have a Subconn connector on one end of the compartment. From each of the battery compartments a Subconn cable leads into the main hull, where the power from the batteries will be hooked in parallel.



From there the power will be distributed to the various devices such as the ATX power supply and power distribution busses. There will be a “key” that will close the main AUV circuitry on the positive lead only. All of the electronics will be housed in a 3-D printed lattice. An Arduino board with a specifically designed shield will be the interface point between the computer and many of the sensors such as the Doppler velocity log, fiber optic gyro, and the 10 electronic speed controllers. The two cameras are connected with the computer using USB cable. We don’t have the hydrophone array yet from Subsonus, however, when we do it will be connected to the computer via a router on the AUV. The AUV will have a fiber optic tether that will be used for program debugging and teleoperation. This will be done via the fiber optic transceiver that will interface with the computer via the router on the AUV.

Components:

Overview

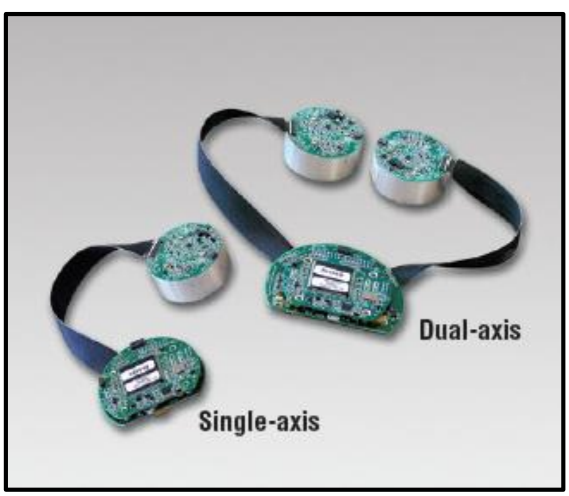
In the sensors and components department, this year’s AUV offers significant advantages over our previous AUV. We are using significantly more precise sensors as inputs for an absolute INS (inertial navigation system). This will give us a much more reliable navigation solution, allowing us to get from mission to mission more accurately and reliably.. The INS solution will be computed on one of the two Teensy 3.1 microprocessors. In addition to computing the IMS solution, the Teensy microprocessors will be used as GIO devices,

talking to the various sensors and controlling the ten thruster speed controllers.

Navigation Sensors

Teledyne Explorer DVL: The DVL is an ultrasonic device with 4 beams. The DVL allows the sensing of depth using time of flight (TOF) of the ping as well as X-Y translation to ~ cm level precision using Doppler shift as well as other signal processing techniques. . The DVL cannot however form a navigation position solution by itself as it cannot sense heading changes. The DVL will be housed in a separate hull to make removal from the AUV quick and easy removal as we will be sharing the DVL with the University of Arizona team.

KVH DSP-1750 single axis Fiber Optic Gyro (FOG) The DSP-1750 FOG provides an ultra-stable angle sensor that is capable keeping drift below 0.1 deg./hr. (one sigma) when properly calibrated under optimal conditions. The gyro has enough stability to accurately measure the rotation rate of the earth and this is zeroed out as part of the initialization process for the sensor. The FOG rate drift is affected by temperature changes so we will let it warm up and the hull temperature to stabilize before starting the mission. The gyro works by sending laser light in opposite directions in a spool of optical fiber and as the spool is rotated with the AUV, an interferometer in the FOG counts the rate of nulls and estimates the rate of angle change. The angle rate is integrated numerically 1000x per second to form the (heading) angle estimate for the navigations system. The FOG must be kept level or it will have an angular rate error proportional to the cosine of the tilt angle away from the level position. The use of a camera stabilizing gimbal system is being currently explored as a way to reduce this error. We will be using the same PNI Trax compass that we used last year as a way to double check and assist the Fiber Optic Gyro. We will also use gimbal position information if it is available.



Vision system: This is comprised of several components.

1. The vision processor (the "main computer"),
2. An HD USB board camera.
3. And the viewing window.

The viewing window is mentioned because is has a significant effect on the field of view of the camera. We elected to use a dome with a depth of 2" and a diameter of 6" to minimize the reduction of FOV underwater that results from using a flat window. This shallow dome has less optical power (less FOV) than a 6" diameter hemisphere..

Other Sensors:
In addition to our major sensors, we also have a variety of other important sensors, like the pressure sensor (for measuring depth), the voltage sensor, the RGB + luminosity sensor, internal hull temperature sensor, and the water detector. The water detector will trigger surfacing and ultimately kill power if a leak is detected. All of these sensors will be read and communicated with through the teensy 3.1's.

Next year we will be adding hydrophone array to our bank of sensors on the robot. Procurement of an Advanced Navigation Subsonus USBL was delayed until August and thus will not arrive in time for this year's competition.

Processors

The main computer this year is an Intel i7 @ 4GHz on an ASUS micro ITX motherboard, with 8 GB RAM. It uses a 240 GB SSD for the important systems and a 1TB HDD for general storage. Key tasks for this processor are data logging, vision processing and task sequencing.

I/O processor: We use two Teensy 3.1 microprocessors as our GPIO devices, connected to the Main PC over USB. They are both mounted on a custom PCB to simplify cable management. The PCB has connectors for all of our devices, like the DVL, the motor controllers, the Gyro, etc. the bidirectional interfaces are mostly asynchronous serial data (RS232 and TTL). Also, there will be standard servo type PWM outputs for the 10 thrusters.

The INS (Inertial Navigation System) processor: Will be one of the two Teensy 3.1 devices. The INS processor reads the raw information from the FOG, DVL and other sensors and forms a navigation solution of the X-Y position, attitude and depth of the AUV in the pool. This navigation solution is used by the Task sequencing processor in order to trigger AUV actions to perform the tasks.

Programming:

The AUV's main computer communicates with the two teensy controllers over a serial connection, through USB. To organize the transfer of data over these serial busses, we designed a packet based communication framework. The channel of communication, in this case serial, implements the abstract class Packet Based Communication. Packet Based Communication includes implementation for buffering incoming data, scanning for packets, verifying the integrity of found packets, responding to packets the require acknowledgement, and sending packets.

To organize the different types of information sent over these channels we designed a Packet framework, where each type of packet is a child of the Packet class. The Packet class contains implementation for storing data, identifying its data type, organizing the preamble, data, and checksum, and computing the checksum. This simplifies designing new packet types, as all you need to do is create a child class of the Packet class, and provide its type number and the name of the packet.

User Interface:

This year's user interface will be done through a webpage. The webpage will be accessible through any other computer on the AUV's local network. The page will be written in JavaScript, allowing the AUV to update video feeds and settings values in real time.

This year's data logging system uses two classes, Data Log and Data Point. As their names imply, one represents a log that will handle writing data, and the other represents a single data point. You simply create a Data Point object and give it a reference to the specific log that you want to record to. Both classes are structured in a way that allows you to create multiple logs and multiple Data Points, The Data Log class has a static method that will let you search a list of all open Data Logs, so that any class that uses a Data Point object does not need to be passed a Data Log object.

We used various other resources for programming the AUV. The AUV itself is running Ubuntu, a common flavor of Linux. Most of our development was done on Cloud9 IDE. We used the RXTX library for our serial communication, and the Open CV libraries for our video recording and computer vision.

Future plans/ Conclusion:

We would like to be the overall winner of the competition in the near future. In order to do this we are solving the various technical and logistical problems in a systematic way to put us in a position to where we will be able to become the overall winner of the competition. We believe that the number one problem is the ability to navigate accurately underwater. The sensors are the foundation of an accurate navigation solution and we have successfully put together a world class set of sensors. Unfortunately, it took most of the season to get all the hardware in hand.

This is why we have focused this year's attention to finishing the new AUV hull and on logging raw sensor and camera data that can be post processed during the off season as part of the development of a robust INS (inertial navigation system) and vision processing system. We also have plans to develop a robust hydrophone system for detecting pingers and solving for acoustic heading. The purpose of this system is for homing on pingers to go to their location as well as using pingers for additional bearing observables in our navigation solution.

With the development of some new technologies that we hope to have fully implemented by then and the software solutions that accompany them, we hope to be that team that wins Robosub!

References:

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DVL:
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Advanced Navigation/ Subsonus:
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