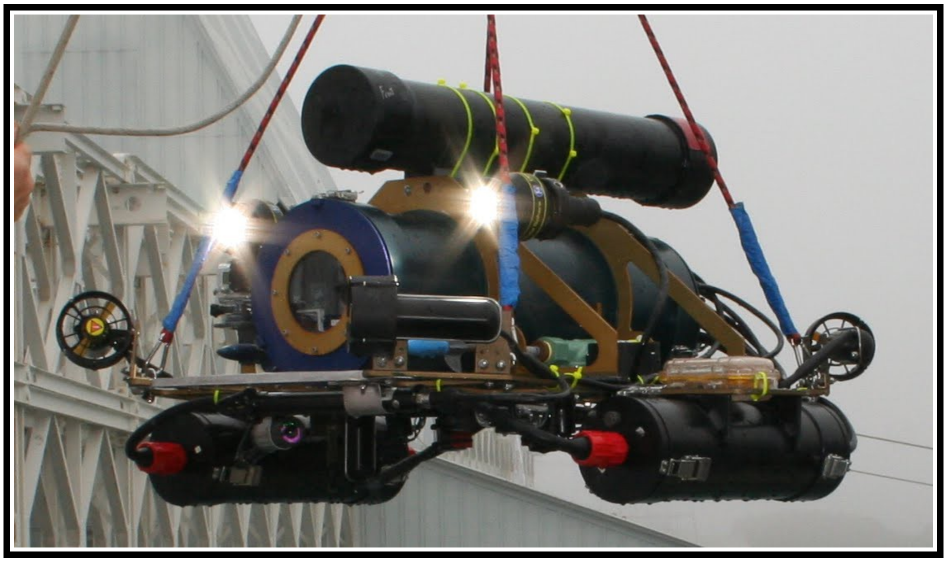
Falcon Robotics AUV Team



Sovereign Falcon 2.4

Abstract

This is Falcon Robotic's 4th year of participation in the Robosub competition, and the team has been taking a systematic approach to eliminating each of the obstacles that stand in the way of winning the competition. In some cases we duplicate what others have done, in others we have come up with workarounds. The vision system is still unreliable and the team continues to develop an auto calibrating system to account for the vast number of light conditions that exist at the venue. Some success was experienced with auto calibration using the forward cameras and a flood fill method based on the average of four independent pixels in the field of view. The downward facing cameras are the focus of our auto calibration this year. The second area of focus is the navigation system. Financial restrictions prevent us from obtaining a Doppler velocity logger, but the team believes that for this venue, another method will be sufficient - a system called optical flow tracking. This is the same concept used by a mouse to track a cursor on a computer screen. Using this method with the AUV as the mouse and the floor of the TRANSDEC facility as the mouse pad, the intent is to use the data collected from the mapping to keep track of the robot's location in a virtual map of the TRANSDEC pool. With these two areas of development we plan to be prepared to make a run for the top spot next year.

Dry Weight: 38.5 Kg **Dimensions:** 109.2cm x 91.4cm x 45.7cm **Max Speed:** .9m/s **Max Depth:** 152m	**Thrusters:** 6 x Seabotix SBT 150, 2.2kg thrust @4.2amps **Cameras:** Allied Vision, 1394b Guppy & LCA **IMUs:** PNI Traxx & Phidget Spacial 3 axis gyro **CPU:** Intel i7 3610QE, 2.3 Ghz, 64 bit, Windows 7

Team Members: *(Students)* Kelly Rexroat, Dianna Valenzuela, Luis Avilos, Bryan Garcia, Jose Martinez, Jesus Parra, Sergio Corral, Jackson Gray, Dalton Dayea, Isela Martinez, Raymundo Nevarez, Eliazar Diaz, Armando Chavez, Samantha Nieto, *(Alumni)* Martin Carranza, Quenan Ruiz, Nayovi Leon, Joach Avitia, Diserae Sanders *(Adults)* Ken Whitley, Glenda Nieto, Jill Jones, Jim Haugen, Faridodin Lajvardi, Srnka Johnson

Team Background

Carl Hayden Community High School is located in central Phoenix, Arizona. Carl Hayden is an inner city school with many of the common inner city school challenges. Some characteristics that further distinguish Hayden include a student population of which 98% qualify for the federally assisted school lunch program, 97% are Hispanic, and an overwhelming majority are first generation immigrants. Many of the students are the first in their family to graduate from high school.

The Falcon Robotics team was formed in 2001 by Allen Cameron and Faridodin "Fredi" Lajvardi. The club was initially created to show students that science and technology can be interesting and exciting but quickly evolved into something far more powerful. The team is now not unlike a school within a school, a "robotics academy" of sorts. Students and mentors spend an average of 3 hours a day, year round, designing and building robots to compete in various competitions. The competitive spirit, a sense of social responsibility, along with the natural aversion to embarrassment drives the learning experience. The program continues to be a huge success! Since its inception, the team has won numerous awards in a variety of competitions from FIRST Robotics *(For Inspiration and Recognition of Science & Technology),* and MATE *(Marine Advanced Technology Education),* ROV Championships, to Pete Conrad Foundation's Spirit of Innovation Awards. The Falcons are always looking for new and challenging ways to be tested, and AUVSI's RoboSub is the latest iteration.

Part of the team's success involves sharing what they have learned with others and promoting curricular and extracurricular STEM *(Science, Technology, Engineering, & Mathematics)* education in over 30 presentations annually. In addition, the team hosts STEM competitions such as FIRST Lego League for grade schools, and NURC *(National Underwater Robotics Challenge)* for competitors ranging from grade school to college. The Falcon Robotics team members not only push themselves into STEM but they bring STEM to as many people as possible.

Team Outreach

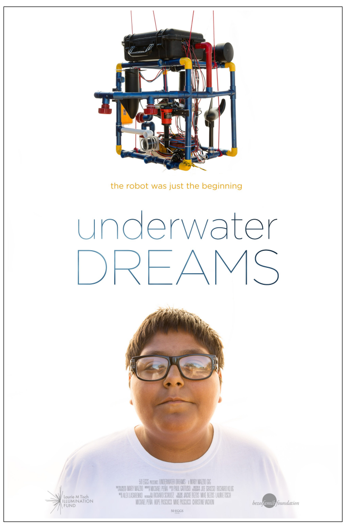
The majority of our school year is focused around the FIRST (For Inspiration & Recognition of Science & Technology) robotics competition, created by inventor Dean Kamen. The Falcon Robotics Team is one of the top teams in the country. The team has won four consecutive FIRST Robotics Arizona Regionals and has qualified for the International Championships. Spreading the STEM education message is one of the primary components of FIRST and we take it seriously.

The team has continued to do educational STEM outreach by holding the 11th annual FIRST Central Lego League Regional for grade school kids in the surrounding area. We also have held our 3rd annual Sci Tech Fair in conjunction with the Arizona Sci Tech Festival, a statewide series of public events to showcase STEM to the public. We bring everything from Tesla Roadsters to quadcopters for the public to see and experience.

The team has also held an underwater robotics competition called NURC for the past 7 years. The National Underwater Robotics Challenge includes elementary school kids all the way up to college and adult teams compete in it. It featured both teleoperated and autonomous vehicles. The team had to take a year off to locate a new venue and will be back in business for 2015.

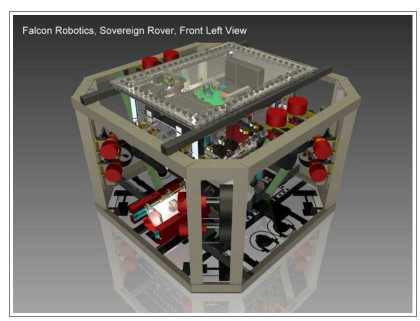
This year we have added impact to our outreach. A book by Josh Davis is coming out this fall. It tells the story of the four students from our team who entered the 2004 MATE ROV competition and won the whole event, beating MIT who placed second. The book follows the boys to the present day. The book can serve as an inspirational tool for other kids in high school.

Furthermore, a feature film based on the four boys' victory at the MATE competition is coming out in late winter. It is being produced by Lionsgate/ Panteleon Films. The script was written by Elissa Matsueda and it was directed by Sean McNamara who directed the movie Soul Surfer. Current robotics team members were directly involved in assisting with the technical aspects of the film. The film, titled Spare Parts, will reach millions of people and hopefully inspire many of them to get involved in STEM activities.

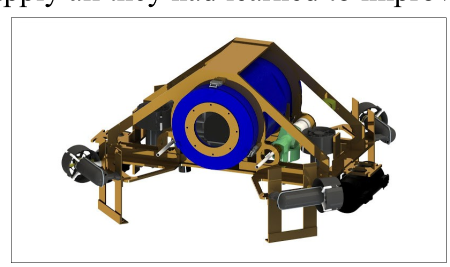


Even further, there is a documentary film called Underwater DREAMs that is currently out in limited engagements throughout the country. It was written, directed and produced by Mary Mazzio. The documentary is a detailed account that explores the four boys' impact on subsequent students at Carl Hayden High School, and the two teachers that shepherded them to their 2004 victory at MATE. The documentary has been getting rave reviews and has been screened by many prestigious organizations such as The Center For American Progress, The League of United Latin American Citizens, The Clinton Global Initiative, the Aspen Ideas Festival, and the National Council of La Raza. Falcon team members are continuously engaged in a tremendous amount of outreach that affects STEM education.

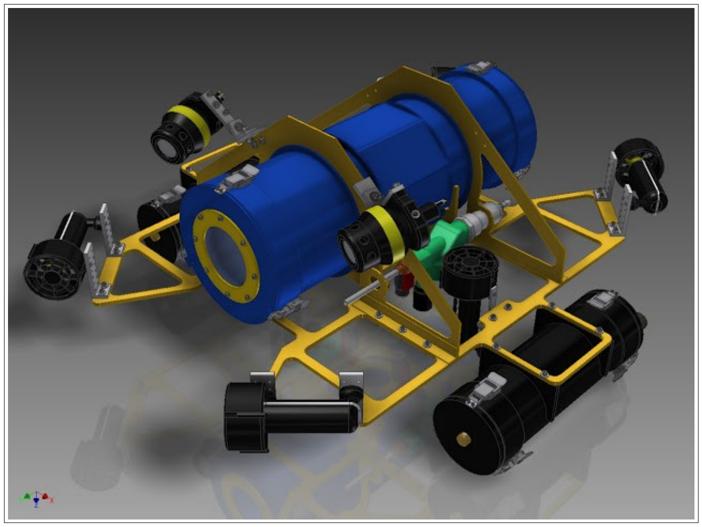
Three Year Summary



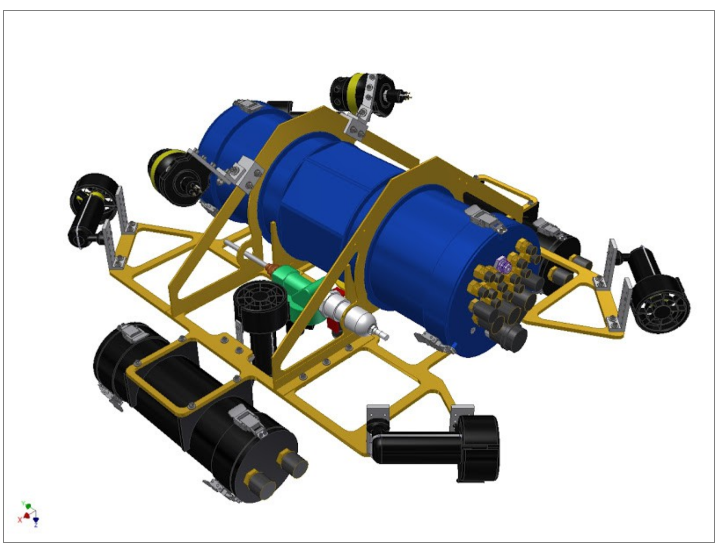
Our first year involvement was primarily to expose the students to the event so as to learn as much as possible about all the other teams and their capabilities. The Falcon Robotics team members asked many questions of the other teams and took copious notes. The team learned about AUV power systems, vision systems, navigation systems and water sealing systems. In the end, during the first year the team was able to “dead reckon” using a gyro to go through the gate and hit a buoy. The experience left the team highly motivated to apply all they had learned to improve for the next year.



In the second year the team decided on a platform, based on what was learned from the first year, that would serve as a base to build on for the next few years as they continued to develop components and software. We managed to get all the components into one main hull and into what we have named a lattice structure. All the electronic components can be removed all at once from the main hull and the AUV and the electronics can be totally separated. The water sealing method was vastly improved by using spring loaded latches eliminating the need for any tools. The vision software was capable of filtering and tracking objects once the settings were calibrated, but would falter if the lighting conditions changed, so more work was needed. Team members also developed accurate PID control of the thrusters giving us a more accurate AUV. We were able to see buoys and the path markers and improve our standing amongst the teams to the middle of the pack. A list of improvements was compiled that would guide the team forward into the third year.



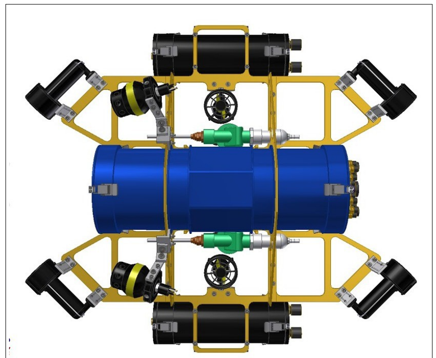
For the third year the team developed an auto calibrating flood fill vision filtering method for the front camera. The background environment for the front camera allowed this, but the bottom camera still relies on having a correct setting that is susceptible to changing light conditions. We also developed a new cooling system for the AUV. It uses the metallic properties of heat conduction and the venturi effect of airflow to remove and dissipate the heat being produced by the CPU and the other electronic components. We no longer have any heat issue with the AUV. The team also decided to implement ultra bright LED totaling 12,000 lumens to see if the increased light would help eliminate or reduce any light variation on the objects we were trying to track with the front cameras. This was only effective up to a distance of 10 feet. For the most part, the lights were ineffective. We also experimented with RTEV, a video filtering system that would cut through the haziness of the water, but were unable to integrate the RTEV system with our AUV code, so we could not use the filtered video. We also decided to record all our data and videos from the runs we made at the event. We could then play back all the data and video in our operator interface as if we were actually running a mission. This was effective, but the video compression was not working properly, so improvement was needed. We also teamed up with the University of Arizona to develop a hydrophone system, but that was not developed in time for this year's event. Our programing skills had improved over the last two years and we were able to make it to the finals! Unfortunately, the sun had not come out all week until our run during the finals. We ended up 8th place. Again we took more notes and decided that we needed a way to have the AUV "know" where it was in the arena so we looked for navigation solutions to implement. Going into this year there are not really any major AUV improvements and the team floundered around trying to implement a Linux platform as opposed to the windows system we had been using. After 6 months we abandoned the Linux platform and returned to our Windows platform. The major push for this attempt to get to



Linux was so we could use Open CV as our vision libraries. Once we failed with Linux we found a way to get Open CV to work in Windows. This killed most of our time this year so we did not progress to the degree we expected. However, we do have a new navigation system to test. This year, as in past years, we will be focusing on what to improve for next year.

Design Rationale

The design of the AUV is one that has evolved over many years of building ROVs and a few years of AUVs. A lightweight skeletal frame holds a metal hull which contains all of the electronics in one housing, except for the batteries, which are located in two side pods safely away from the electronics. The electronics are mounted in a removable lattice structure that allows for easy access. The thruster configuration is one we call vector drive. It consists of 4 horizontal thrusters mounted diagonally to the frame in 45 degree angles and two vertical thrusters. This configuration give the AUV the ability to move in any direction without having to rotate. As mentioned earlier, the team is trying to come up with a platform that will give us multiple years of operation without the need to rebuild an AUV yearly. This is to allow the software to be the point of emphasis to reach the AUV maximum capabilities.



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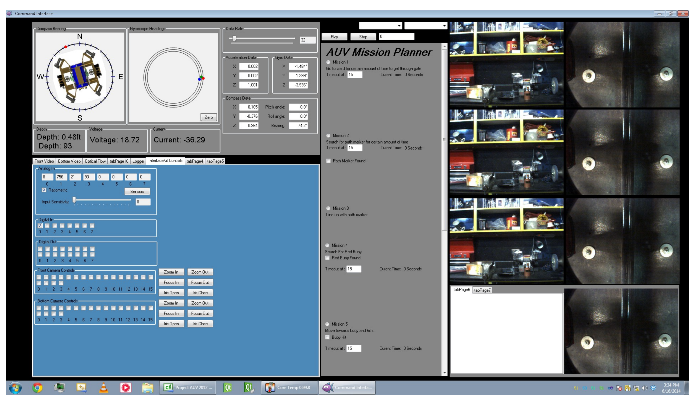
Mission Planner

The mission planner last year was flawed in many ways. For starters, we had no timeouts for each mission. For example, the AUV was programmed to move straight until it detected a line. If no line was ever detected, it would keep going forward in an infinite loop and never advance to the next part of the mission. The mission planner was filled with these scenarios.

This year, the team has completely redone the mission planner. Each mission is now controlled by a timer that, when a task is not completed in a certain time frame, the robot will skip the step and continue to the next task on the mission planner. This will hopefully allow our AUV to continue its mission.



Command Interface

The command interface is a giant form where all the controls and data for the AUV are displayed and can be manipulated. Having everything needed for the AUV on one compact form allows for easy access to anything needing to be altered or seen.

Vision System

This year, we chose to use the EmguCV vision libraries in place of aForge, which was used last year. We chose Emgu because of it's ease of use and increased capabilities. Emgu is a very powerful group of vision libraries, and is an adapted version of OpenCV, with .NET support.

The team organized all of the filter algorithms into a single class, which helps keep the code organized. Each filter method in the class takes an image as a parameter and returns an image, along with any information variables that the filter needs. When we develop these filters, we have a separate program that we build and test the filters on, which allows us to easily determine which values work

best for our robot's environment, making implementation much smoother.

Last year for the forward vision the team used a flood fill method to isolate the buoys we were looking for. We had a fair amount of success with this method, however, for the bottom camera where the floor of the pool had too varied a color surface, flood fill method did not work.

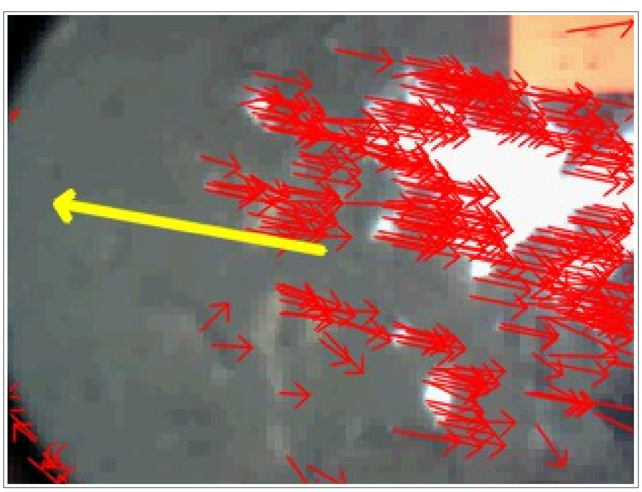
For this year's competition, the team decided to improve our buoy tracking algorithms. In the previous year, our robot was doing a fine job of tracking buoys, until the sun came out. Our robot was calibrated for a set lighting condition, and none others. When the lighting changed, our robot did not know what to do. This year we upgraded our tracking with filter scanning, where the robot scans through a set of filters calibrated for different lighting conditions, until it has found the buoy.

Video/Data Logging System

Last year, the team decided to start saving the video feeds and data from the AUV for future use in testing new vision algorithms. We ran into a slight issue last year that made the video logging almost useless. The video we saved ended up being improperly compressed from the saving process. The video was a lot less detailed than the actual video feed from the AUV. That being said, any new vision algorithms that we made worked better on the saved video than the actual feed from the AUV since the saved videos had less detail. This was a problem throughout the competition last year so we ultimately stopped using the archived video for adjusting filters for the camera feed.

This year, the team is giving the video/data logging another shot. The team concluded from last year that the compression problem was an issue with the video codec we were using to save the video. By switching codecs, we hope to fix the compression problem and allow for our saved videos to be of actual use for calibrating the vision filters.

Optical Flow (our newest innovation)



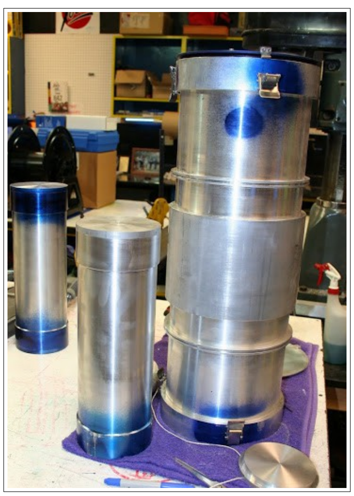
In previous years, our robot navigated the pool by following a set of steps that we had to pre-program and test. These steps were often simply dead-reckoning, telling the robot to move forward a given velocity until a visual acquisition by one of two cameras takes over. Time outs were not in place in case the AUV missed finding the visual cue. This was often an unwieldy way to get from point A to point B.

This year, the team developed Optical Flow, a vision tracking algorithm that will allow us to keep track of the robot's position in the pool. Using the data from Optical Flow as feedback for a PID algorithm, the robot will be able to accurately move between waypoints on a virtual map of the pool. These waypoints will be correspond to missions and objectives in the pool, that were programmed before our runs.

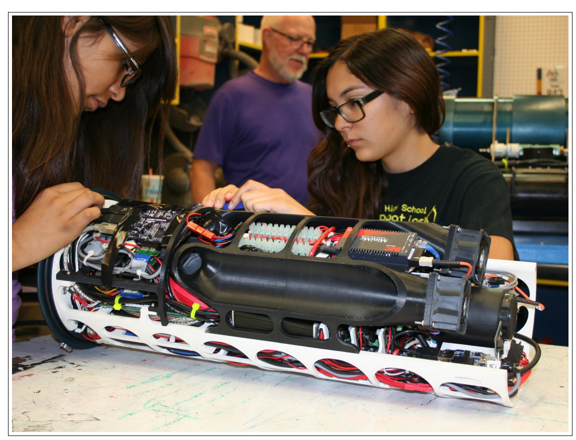
Optical Flow is a collection of steps that analyzes the downward facing video for movement. It's first step is to take both the current image and the previous image, and analyze them for trackable points, which are stored in an array of points. It then sorts the arrays, so that the point at index X in the current image is the same point found at index X in the previous image. From here it is a simple matter to calculate the average shift of the point, which is equivalent to the shift between the two images given. This shift represents the velocity of the robot for that particular sample, in both the X and the Y axis, and by tracking that velocity, we can determine the robot's current location in the pool. It is not unlike the way a mouse tracks on a mouse pad to control a cursor on a computer screen. The team hopes to have this process of navigation balance out the advantage the teams that use Doppler velocity Loggers have.

Mechanical

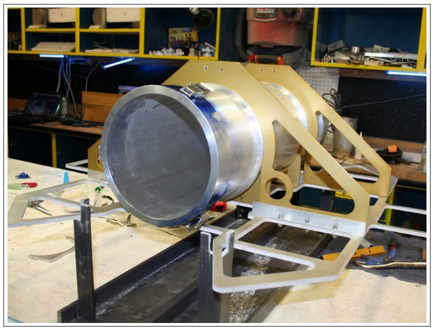
Hull For the water-tight electronics compartment, something easy to open and close was desired. The quality of being simple to machine was essential because the team had minimal access to machining equipment. Aluminum was ideal because it is an excellent heat conductor, allowing the electronics to keep cool when the hull is in contact with water. For these reasons the team selected an 8" aluminum pipe, ½" thick, and machined it to meet requirements. Two ½" thick circular lids were machined so that most of the lid fits inside the pipe leaving an 1/8" lip. An o-ring was fitted over the part of the lid that inserts into the hull creating an o-ring seal against the lip of the lid and the hull face itself. This allows for a larger margin of error, unlike other methods that require accuracy up to a thousandth of an inch. The lids are sealed to the hull using three spring loaded latches. Since the cameras are located inside our hull we needed two light openings, one in front on one of the lids and one facing down into the middle of the main hull. Each opening is then covered by a ¼" thick piece of Lexan. To prevent leakage we put an o-ring groove around the openings to create a seal between the glass and the aluminum. This allows the cameras to be placed in the hull and also negates the need to machine additional water- tight compartments. The hull was then thinned to reduce mass.



Electronics Lattice To hold all the electronic components, the team designed what is called a lattice structure. All the components were mounted to this structure and then the lattice is inserted into the main hull. The end of the lattice is attached to one of the main hull end caps. This way the whole lattice structure can be removed so that it can be swapped out for another to ease the ability of the technicians to do repairs.



Battery Compartments The battery compartments are similar to the hull in structure. They consist of 3" diameter by ¼" thick by 6.5" long aluminum pipes. Like the hull, they have two machined circular lids that are 3" in diameter and ½" thick. Half of the lid is machined down to 2.5" so that an o-ring can be placed around it to create an o-ring seal. Unlike the hull, the battery compartment latches could not be mounted directly onto the compartment because of the sharp curve of the compartment. To compensate for the sharp curve, washers were made out of ABS pipe that had one side flat and the other curved to match the compartment, allowing the flat latches to be mounted to a curved compartment without modifications to either. The center of the compartment was thinned to reduce mass.



AUV Frame The AUV frame consists of three sections. The main section, which is horizontal, holds everything, and two minor sections, which are perpendicular to the main section, are used to keep the hull in its proper place. An internal frame was selected in order to reduce weight and retain strength. The main section has six thruster mounts, four of which are mounted horizontally at 45 degree angles to each other allowing for vector drive and two that are mounted vertically for vertical movement.

Torpedoes The torpedo launching mechanism uses compressed air to fire the torpedo. The compressed air is stored in a 1" diameter, 4" long PVC pipe on the input side of a 24 volt activated inline sprinkler valve, and a ¼" hollow tube is attached to the output side of the valve. The torpedo itself is a modified child's pool toy that fits over the ¼" tube awaiting the release of the compressed air to fire it. This is a low cost and simple system that was easy to design and construct and is already watertight. The system can be charged with compressed air using a portable compressor via the Schrader valve on the PVC pipe.

Electrical

The AUV utilizes 24 volts to power the thrusters and to power an ATX power supply which breaks down the voltage into the lesser voltages needed by all the electronic devices. The batteries are located in two battery pods and they are connected in parallel with the capacity needed to complete the mission.

Future Pans

The team will be looking at a new feedback loop method brought to our attention by Bill Nye. We happened to bump into him at the White House Science Fair and he suggested we give this other method, called PDF, or Pseudo-Derivative Feedback Control, a try. He suggested that we might get better results and it is easier to implement that normal PID, which is what most people use for a feedback loop. It was developed by Richard M. Phelan at Cornell University.

Components

Device	Vendor and specification
CPU	Intel Sandy Bridge processor
Marker Dropper	Orbit Solenoid from 24v Sprinkler valve
Tether	Fiber Optic Cable Corporation , with Seacon terminus

Tether Reel	Hanny Reels,
Fiber Optic System	IMC Networks fiber optic bi directional transceivers
FORJ	Fiber Optic Rotary Joint, Princetel
Lights	Deep Sea Power & Light, 6000 Lumens
Claw	Seabotix. Three jaw grabber
Compass	PNI TRAX AHSR Module
Gyro	Phidget compass 3 axis, gyroscope 3 axis, +/- 4 gaus, +/- 400 degrees/ sec
Light Senor	Phidget Light Sensor, 1-1000 lux
Motor Control	Phidget 28vdc Motor Control
Thrusters	Seabotix BTD 150
Pressure Sensor	UTOP Pressure Sensor
Cameras	Allied Vision, Guppy Fire wire
Lens	Computar 3 motorized lens
Main Power Supply	Ma-ATX 250 watts
Current Meter	Phidget 50 amp
Voltage Meter	Phidget 30vdc
Relays	Phidget interface kit 0/0/4, 100vdc 5amps
Relays	Phidget interface kit 0/0/8, 2amps
USB Interface	Phidget interface kit 8/8/8, 8 analog, 8 digital inputs and 8 digital outputs
RTEV	Real Time Enhanced Video, ZMICRO
HDMI Converter	Grass valley, ADVC HD50 fire wire to HDMI
Fire Wire Card	Sonnet 3 port pci card
Aux Power	Vicor 5v output power supply, 24 v input
Aux Camera	LCA color camera 560 lines
Connectors	Dean's Ultra and micro plugs
Batteries	Thunder Power 5000mAh, 25.9vdc
Connectors	Subconn circular series

Sources

PDF (http://stablesimulations.com/technotes/pdf.html)

Optical Flow (http://robots.stanford.edu/cs223b05/notes/CS%20223-B%20T1%20stavens_opencv_optical_flow.pdf)

Acknowledgments

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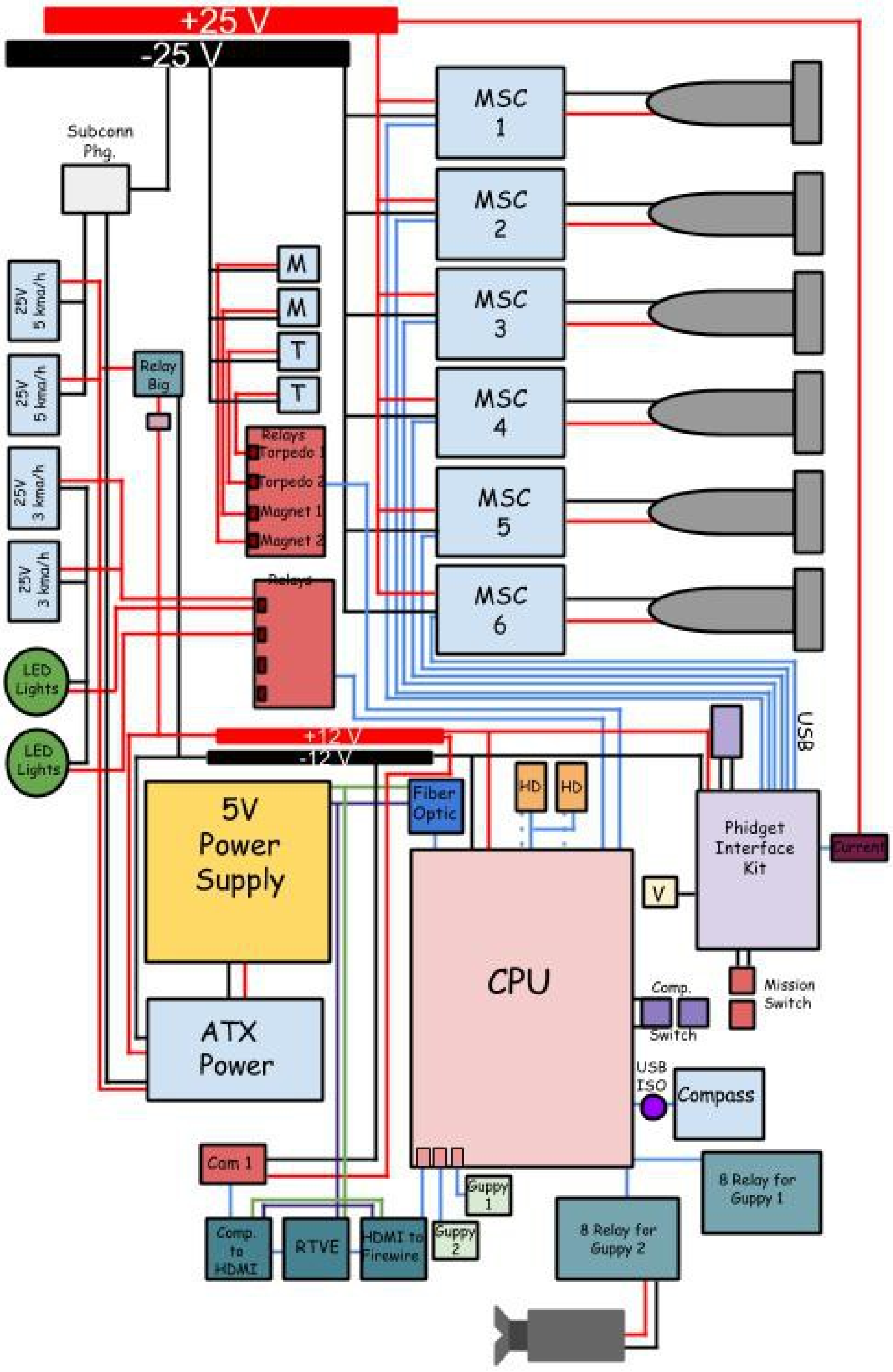
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