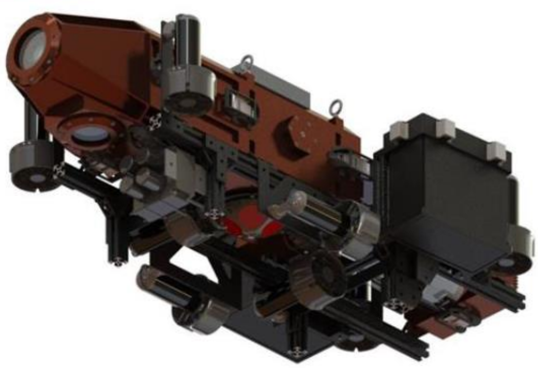
Hail-HYDRAS: Design and Implementation of a Hydrophone and Direction Rendering Analysis System (HYDRAS) for San Diego State University Mechatronics' Defiance Robotics Submarine

MECHATRONICS

SAN DIEGO STATE UNIVERSITY

HYDRAS Senior Design Project



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October 8th 2015

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ABSTRACT

San Diego State University's (SDSU) Mechatronics Club exceeded all expectations earlier this year when their robotic submarine (RoboSub) finished the competition in first place out of forty international collegiate and high school RoboSub teams. Though the Mechatronics Club's RoboSub performed exceptionally well, the team still lacks a functional passive SONAR system that is able to triangulate two pingers emitting frequencies in the range of 25 kHz to 40 kHz, in 0.5 kHz intervals. During the competition, two pingers will be emitting frequencies within the 25 kHz to 40 kHz range and the passive SONAR system must accurately detect the target pinger, ignore the decoy pinger, and provide three dimensional relative bearing (distance, heading) and elevation to the RoboSub's main computer via RS-232 to allow for navigation within a four foot radius. The goal of the Hail-HYDRAS senior design team is to provide the Mechatronics Club a passive SONAR system that utilizes the RoboSub's four Sparton Hydrophones to differentiate between the two signals and determine the direction of arrival for the signal corresponding to the target frequency.

PRODUCT DESCRIPTION

Hail-HYDRAS is a senior design team made up of Electrical and Computer Engineering students from SDSU that has been tasked with designing and implementing a passive SONAR system for the SDSU Mechatronics Club's Defiance RoboSub. The Mechatronics Club is a robotics team that builds and operates an Autonomous Underwater Vehicle (AUV) to compete in the Association for Unmanned Vehicle Systems International (AUVSI) annual RoboSub competition. The goal of Hail-HYDRAS is to provide the Mechatronics Club a passive SONAR system that utilizes the RoboSub's four Sparton Hydrophones to detect and differentiate between two separate pinger signals and provide navigation to the target pinger by determining its relative bearing and elevation.

During the RoboSub competition, each Teledyne Benthos ALP-365 acoustic pinger from two different locations within the competition pool will be producing signals with frequencies within the range of 25 kHz to 40 kHz, in 0.5 kHz intervals. The event judges will provide which frequency is the target and which is the decoy on the day of the event. The goal of our passive SONAR system is to accurately detect the target pinger, ignore the decoy pinger, and provide the bearing and elevation of the target pinger relative to the RoboSub to the RoboSub's main computer via an RS-232 connection to allow for navigation within a four-foot radius. Successful completion of the competition event requires the RoboSub to determine and navigate to the location of the target pinger, then surface inside a nine-foot diameter octagon located directly above the pinger. Figure 1 shows an example of the area that the RoboSub needs to submerge on competition day. The area is marked on the surface with a floating ½" PCV pipe. An acoustic pinger is mounted on a pole in the center of the area. A sample box is positioned directly above the pinger.

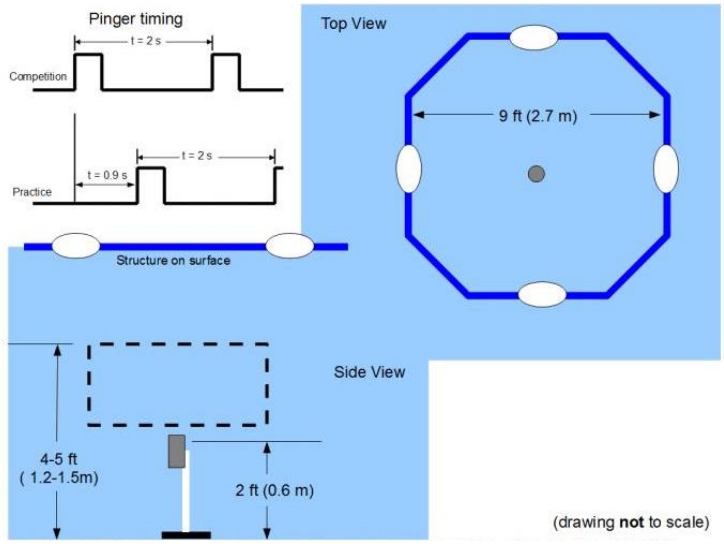

Figure 1: Pinger Recovery Area

To accomplish our design goals, we will be creating a Hydrophone and Direction Rendering Analysis System (HYDRAS) on a four layer mixed signal Printed Circuit Board (PCB) that will include a Signal Processing Suite to condition the analog signals such that only the target frequency will be detected. The target signal and its time delay will then be sampled with respect to two sensors, providing us with the distance the sound wave travelled in the direction of propagation. A second constant distance (between the two sensors) coupled with the inherent 90 degree angle between the direction of arrival and the plane wave provides the information necessary to calculate the direction of arrival with respect to a plane normal to the submarine.

Additionally, Hail-HYDRAS will build a Graphical User Interface (GUI) for the passive SONAR system that will take in all data packets from the HYDRAS board and display that information graphically and textually. The GUI will also be in charge of initiating COMM ports and embedded variables that may need to be adjusted for various scenarios and competition requirements. The GUI will also allow us to digitally filter the hydrophone array and calculate the horizontal and vertical phase angles to determine the bearing, heading, angle of inclination, and time of the arrival of the sub relative to the target pinger.

DESIGN

Pinger Control Design

The Robosub team currently uses Teledyne Benthos' ALP-365 Pingers to test their hydrophone array. These pingers are currently activated by being submerged in water, causing a decrease in resistance between two exposed terminals. Unfortunately, this method does not offer a precise way to control the start time of the pingers, which is necessary for the Robosub's purposes. While tracing the pingers circuit, we found a jumper that bypasses the water activation, allowing the pinger to start and stop by installing/removing batteries. Though space is limited, there is enough room to fit a normally closed (NC) SPST CMOS Analog Switch between the bypass jumper terminals, one in each of the pingers. With these switches in place we could open the pinger housings and connect a microcontroller to them, allowing us to control the closing of the switches, thus controlling the pinger start time. Once the pingers have been initiated, the switch's enable input from the external microcontroller can be disconnected while maintaining their normally closed position. The microcontroller will allow for easy control over the delay between pinger start times. This method also would not affect the original intended starting method; placing the jumper in the appropriate position will still allow the pinger to be water activated, as originally designed. Figure 2 illustrates the control circuit to be designed.

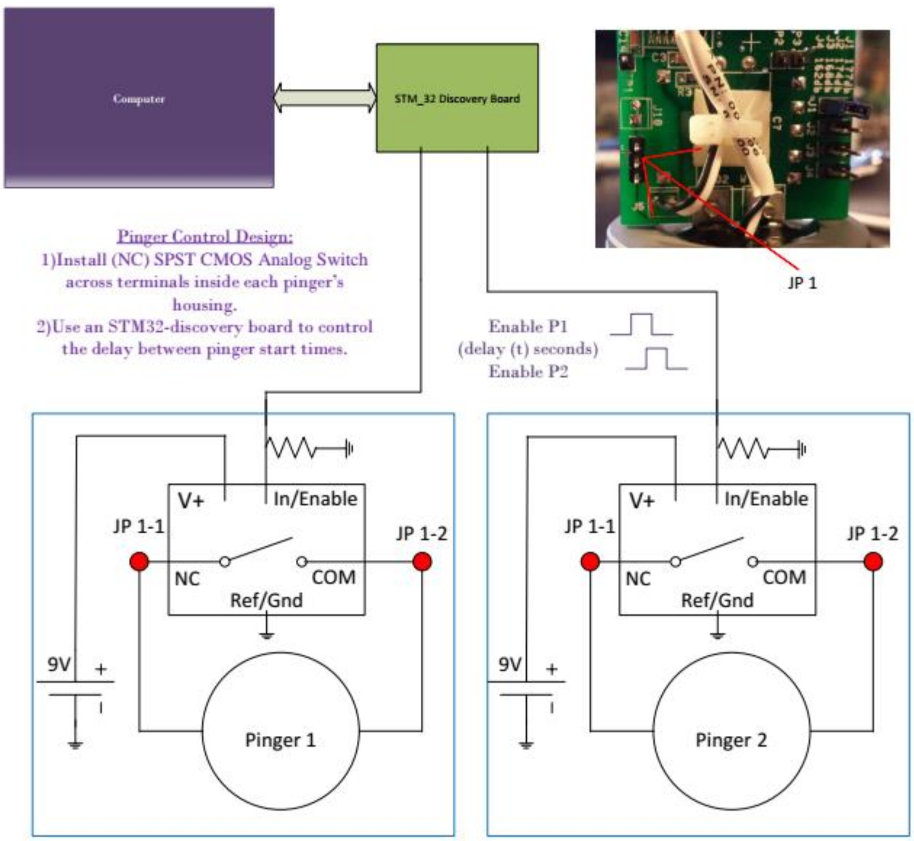

Figure 2: Pinger Control Circuit

System Block Diagram

Figure 3 shows the block diagram for the proposed HYDRAS board. The HYDRAS board will take four hydrophone signals and will send them to two different systems for measurements and analysis.

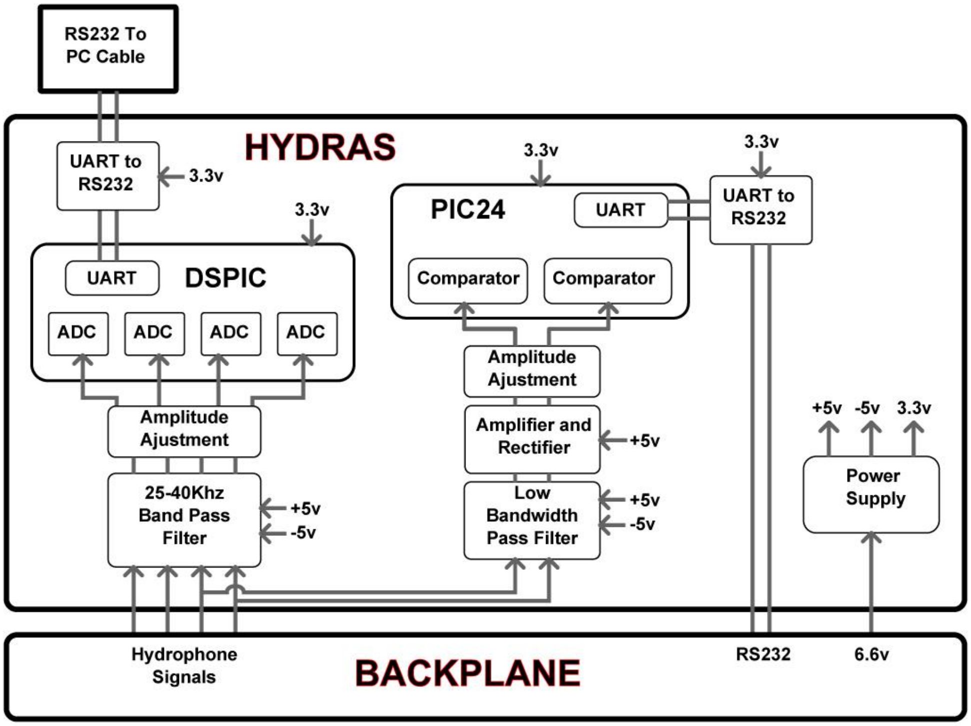

Figure 3: Hardware Block Diagram

The DSPIC system will take the sinusoidal 0 VDC centered signals and put them through a Band Bass Filter followed by an amplitude adjustment section. The signals will have a DC offset added to the signals as well as adjustment to the amplitude of the signals so that all signals are identical in amplitude when arriving at the ADCs. The ADCs will sample the sinusoidal signals and send the digital readings to the submarines commuter using an external RS-232 cable. The computer will then take the unprocessed ADC readings and analyze the signals for heading information.

The PIC24 system takes two hydrophone signals and will pit them through a Low Pass Filter followed by an amplification, rectification stage, and amplitude adjustment stage to turn the signals into a DC signal to be read by the Comparators. The Comparators will monitor for a low to high signal change and will measure the difference of arrival time between the signals, then it will calculate the heading of the pingers. The heading data will be transmitted via RS-232 through the backplane connection.

The HYDRAS board is connected to the submarine via a backplane that uses a standard 70 pin socket. Figure 4 shows the pinout standard connector format. Figure 5 is the illustration of the Hydras circuit card to be designed.

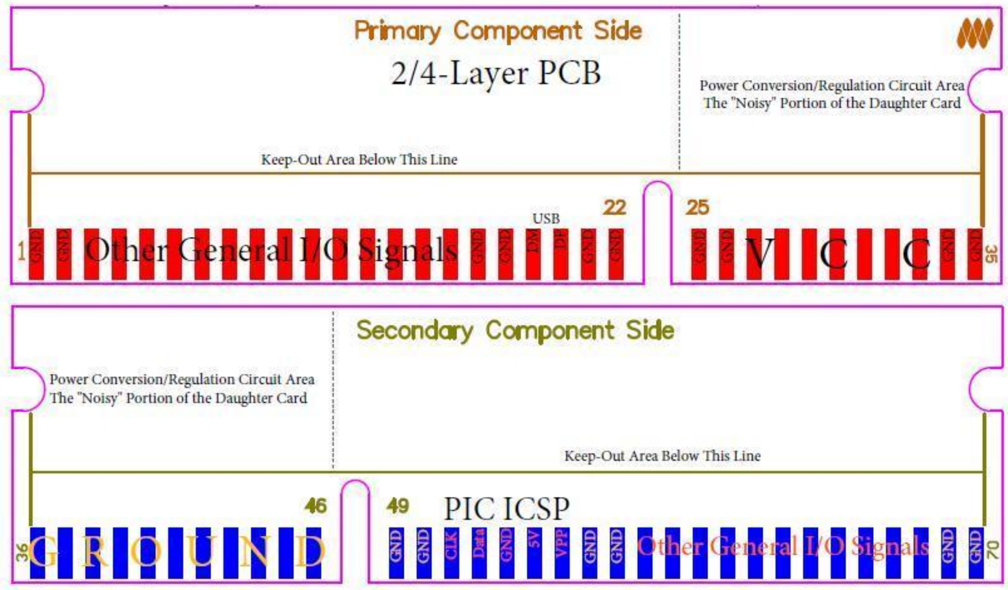

Figure 4: HYDRAS Board Pinout

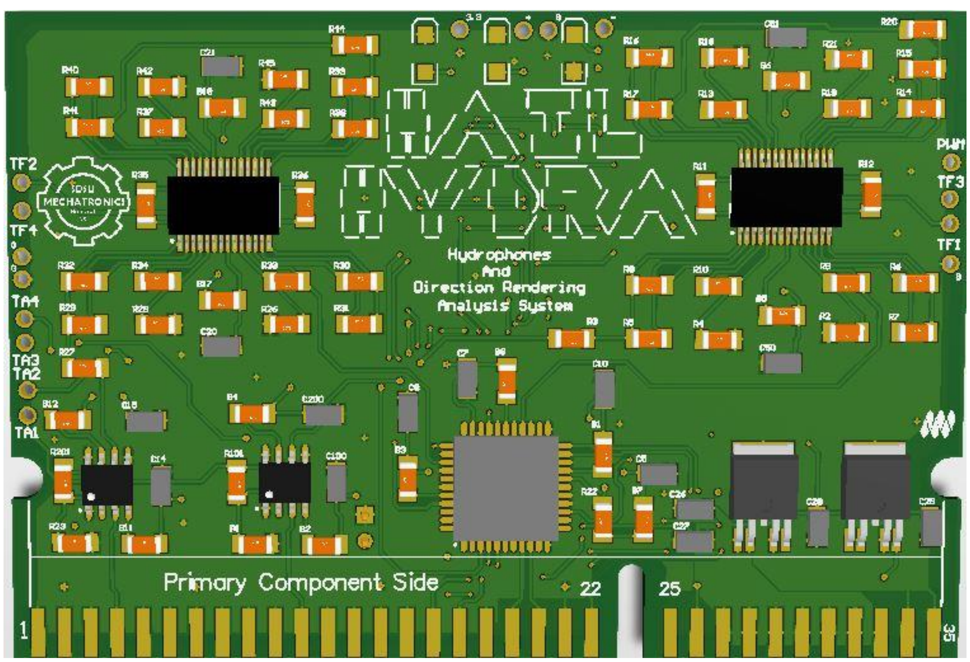

Figure 5: HYDRAS Circuit Card

Python GUI Software Suite

The graphical user interface (GUI) show in Figure 6 will be used for three purposes. First, we will be using the GUI as our main visual display to show the RoboSub's data, information, location, as well as the pinger's location. This will include four graphs and they will display the bearing, heading, distance, phase delay and arrival time of the hydrophone array. This will also include textual output data that will enable us to understand more concretely. We will be able to log this data and export it in a desired file format to view/debug at a later time. Second, we will have a section on the GUI to interact with, and manipulate the embedded hardware. For example, we will be able to initialize the target frequency, water temperature, sampling rate, COM ports, Baud rate, etc. This will give us more control over changing what we need for any competition requirements. Lastly, we will be able to manipulate how the data is displayed on the graphs, including altering time and variable axis, zoom, the number of hydrophone signals to output. It will also provide the external functions to users such as pause, record, export, take screenshot, and save.

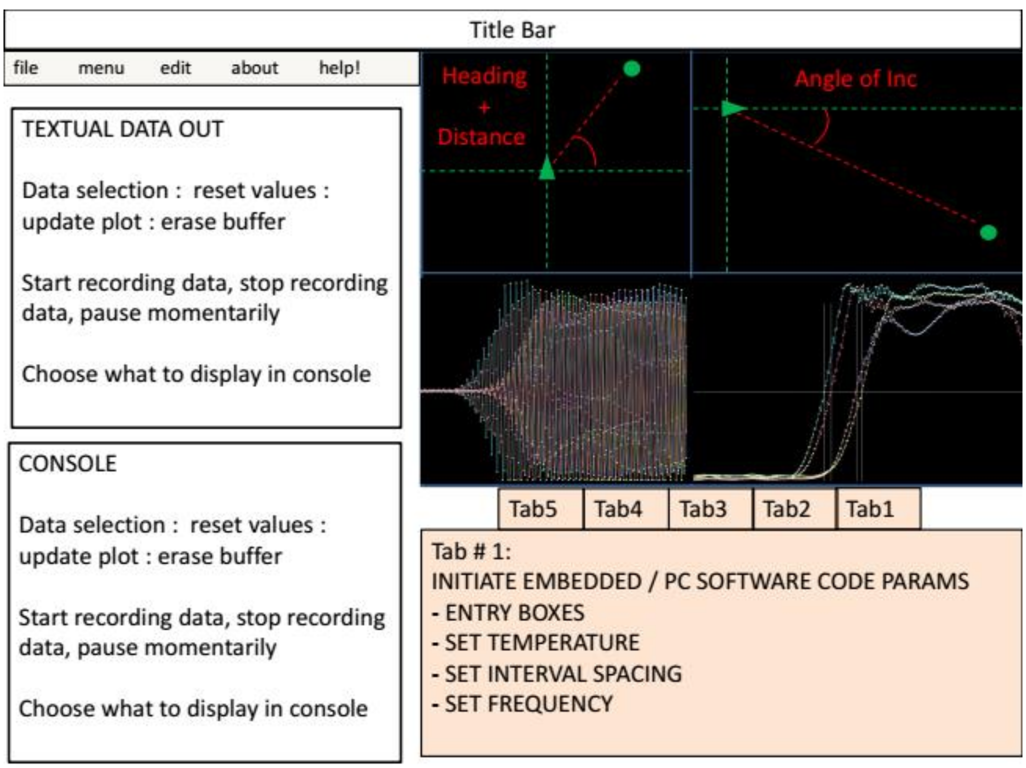

Figure 6: Python GUI

Figure 7 illustrates the block diagram for the Digital Signal Processing solution implemented in Python. From the RS-232 to PC connector, the four hydrophones signals are sent immediately through a digital Band Pass Filter in Python that attenuate any potential noise in the signal. The filtered signal is then passed through a Hilbert Transform Filter that converts the real signal into a complex sinusoid signal that has a real and imaginary part. This in turn provides us with a signal that has a constant magnitude with a varying phase as data is being collected. Because all four pingers change at the same rate, we are then able to apply the conjugate product to get the phase angle between hydrophones. By applying Trigonometry principles, the phase angle allows us determine the angle of inclination and bearing. One important thing to note is that the bearings that we calculate will not be able to scan a full 180° range because the spacing of the hydrophones will be greater than a wavelength of the pinger's signal. Our goal is to be able to accurately calculate the bearing of plus or minus 50° from the heading of the RoboSub at frequencies spaced 0.5kHz from 25 to 40kHz.

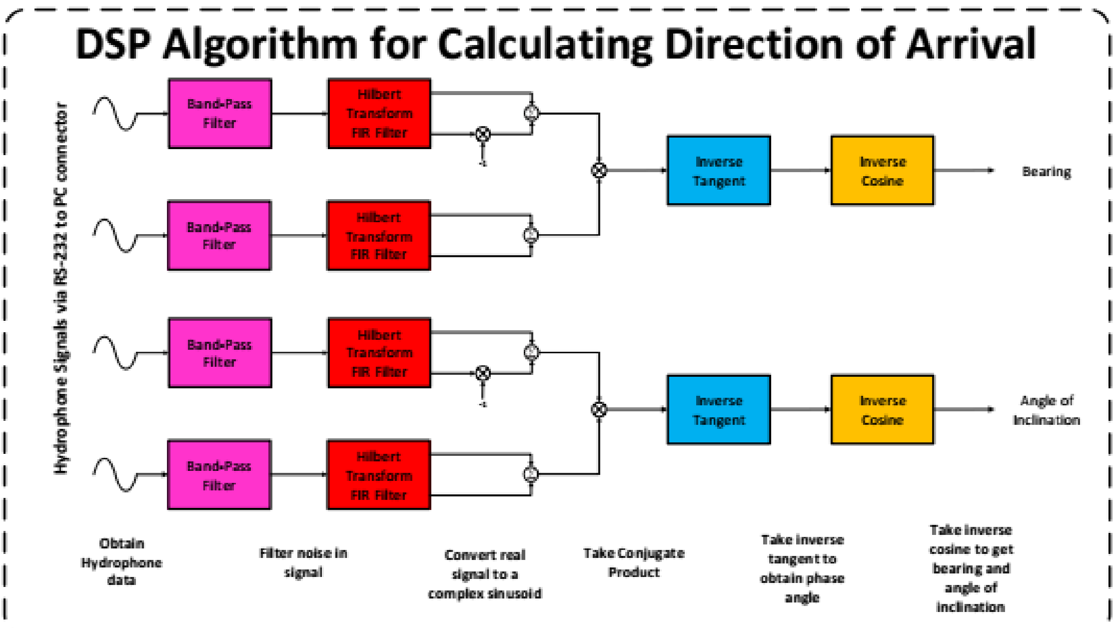

Figure 7: DSP Algorithm

Performance Requirements

Hardware

The Printed Circuit Board (PCB) must:

- Provide clean power regulation from a dirty 6.5 VDC input rail to the various components into the PCB (Printed Circuit Board).

The embedded system must:

- Capture a pulse of sound or "ping". The distance of the object will be calculated based on the dynamic value of the speed of sound and the current temperature of the water.
- Calculate heading, distance, and angle of inclination of the target pingers within 5 degree ambiguity.
- Create Subsystem setting that sets the two pingers with a two-second period.

- Package the data so we can send a stream of values (approximately 50 periods) to the Software Team.
- Send solution data to the computer via an RS-232 serial port.
- Condition analog signals while maintaining signal integrity.

Software

The software side needs to generate a solution set parallel to the embedded side. The purpose of this is to compare both solutions as well as “tune” the embedded side solution for optimum accuracy. This will require that the software side receives packetized sample data from the embedded side for each hydrophone via RS232. The computer will then process that data and generate a heading, distance, and angle of inclination solution. Two approaches will be employed to generate a solution set: phase shift and time of arrival. The software GUI will allow the user to visually see the graphical solution generated by both approaches. The two pingers emit a signal approximately every second. So the software needs to be able to generate a solution set for each received ping. This will require that all of the sampled hydrophone data be transferred over RS-232 in an efficient manner. The software GUI will also need to be able to specify configuration parameters for the embedded side. Those include, but are not limited to, setting the target frequency, specifying water temperature and pingers’ interval timing, and setting a sample threshold level. Lastly, a data logging system will be able to save values and commands when the GUI application is closed and reload those values and commands when the application is reopened.

TESTING & VERIFICATION

Testing Procedures

Signal Integrity of PCB

Signal integrity testing will be done to ensure that the signals exiting the four hydrophone outputs and entering each component read the same magnitude and phase. A 1-volt sinusoid signal with 2.5 kHz frequency will be passed through each of the 4 input on the daughter card connector with a scope displaying the signal. Then, the output end of each component will be connected to a scope. The voltage and phase differences will be measured and compared (4 components on the Communication Suite will be compared to each other, and 2 components on the Signal Processing Suite will be also compared to each other.) If there are errors in magnitude and phase between the signals, the precision pots on the daughter card will be adjusted to match the signal traces.

RS-232 Configuration

To configure RS232 communication on the computer, the software GUI will first identify available COM ports. The user will have the option to select which COM port to connect to, as well as specify the baud rate, and timeout.

Underwater Testing

Tests to determine the reliability of the software and embedded system solutions will be conducted at the San Diego State University Aquaplex. The underwater pinger control circuit will be placed in the pool with a known bearing relative to the heading of the RoboSub. Tests for the bearing will be done from -45˚ to 45˚ in steps of 15˚ at frequencies between 25 to 40kHz. The angles of inclination will be kept constant during these tests since the angle of inclination is not as important for navigation. The solutions from the Communication Suites and Signal Processing Suite will be compared to validate the bearing results. If both solutions align with one another, the information will be transmitted back to the backplane to position the RoboSub in the direction of the pinger. If both solutions don't align with each other, changes will be made and it will be retested until both solutions align with each other.

Benchmarks

Our redesign of the passive SONAR system features changes and improvements to the previous design. First the new board takes advantage of better hardware that operates at a higher sampling rate of 1 MHz versus 333 KHz before. This in turn provides us with more data for accurately determining the direction of arrival. To be compatible with the RoboSub's custom backplane the new daughter card uses the same form factor and pin-out reference. Additionally, the original square hydrophone array from last year's sub has also been expanded to two sets of hydrophones located on both sides of the RoboSub. This is a significant change since it allows our time domain solution to have a resolution of 0.25 degrees of the bearing versus 5.67 degrees from previous year.

Another significant change is our new system offers a software suite capable of determining the direction of arrival through advanced digital signal processing methods. Using the sampled data from the hydrophones the software suite can now calculate the bearing and the angle of inclination of the target pinger. This is a critical change since it provides another solution that will validate where to position the RoboSub. Moreover, the Software Team's GUI also graphically displays the data to assist in underwater testing and verification. The GUI is built using Python programming platform as in the original software system. Also, to assist in underwater testing, a pinger control circuit will be developed to simulate the delayed pings that the hydrophones will need to measure on competition day.

PROJECT MANAGEMENT

Project Plan

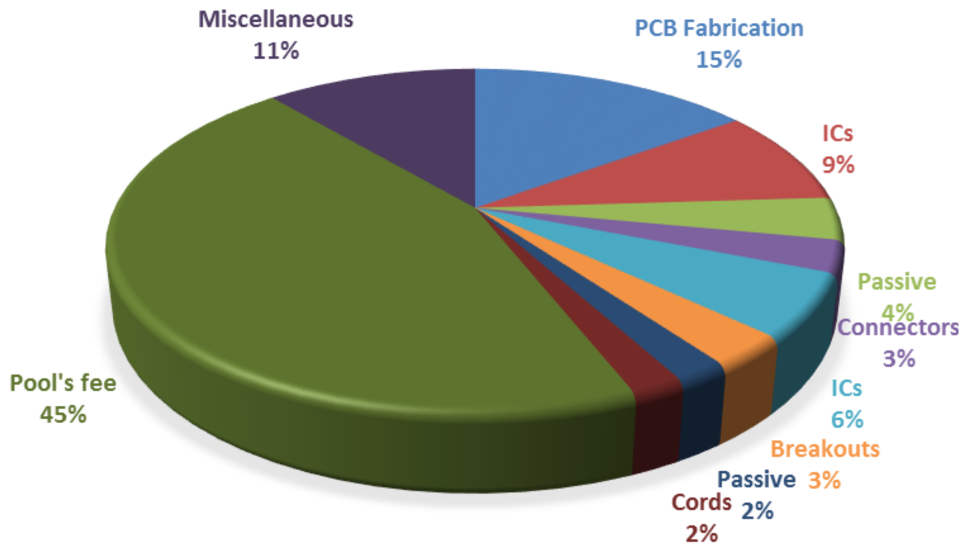

Figure 8: Budget

Figure 8 shows the breakdown of how plan to allocate resources for the project. Approximately 55% of the funds will be used for designing and building the HYDRAS daughter card. The other 45% will be used for buying time to test the passive sonar system at the Aquaplex at SDSU. No expenses will be incurred on the software side to build the GUI. If in the event that PCB does not pass on first inspection funds from the testing budget will be redistributed to re-spin the board.

	Cost Requirement	Allocation
PCB Fabrication		$750
Components	ICs	$450
	Passive	$200
	Connectors	$150
Prototyping	ICs	$300
	Breakouts	$150
	Passive	$100
Discretionary	Cords	$100
Testing	Pool's fee	$2,240
Total		**$5,000**

Milestones

Figure 9: Hardware Gantt Chart

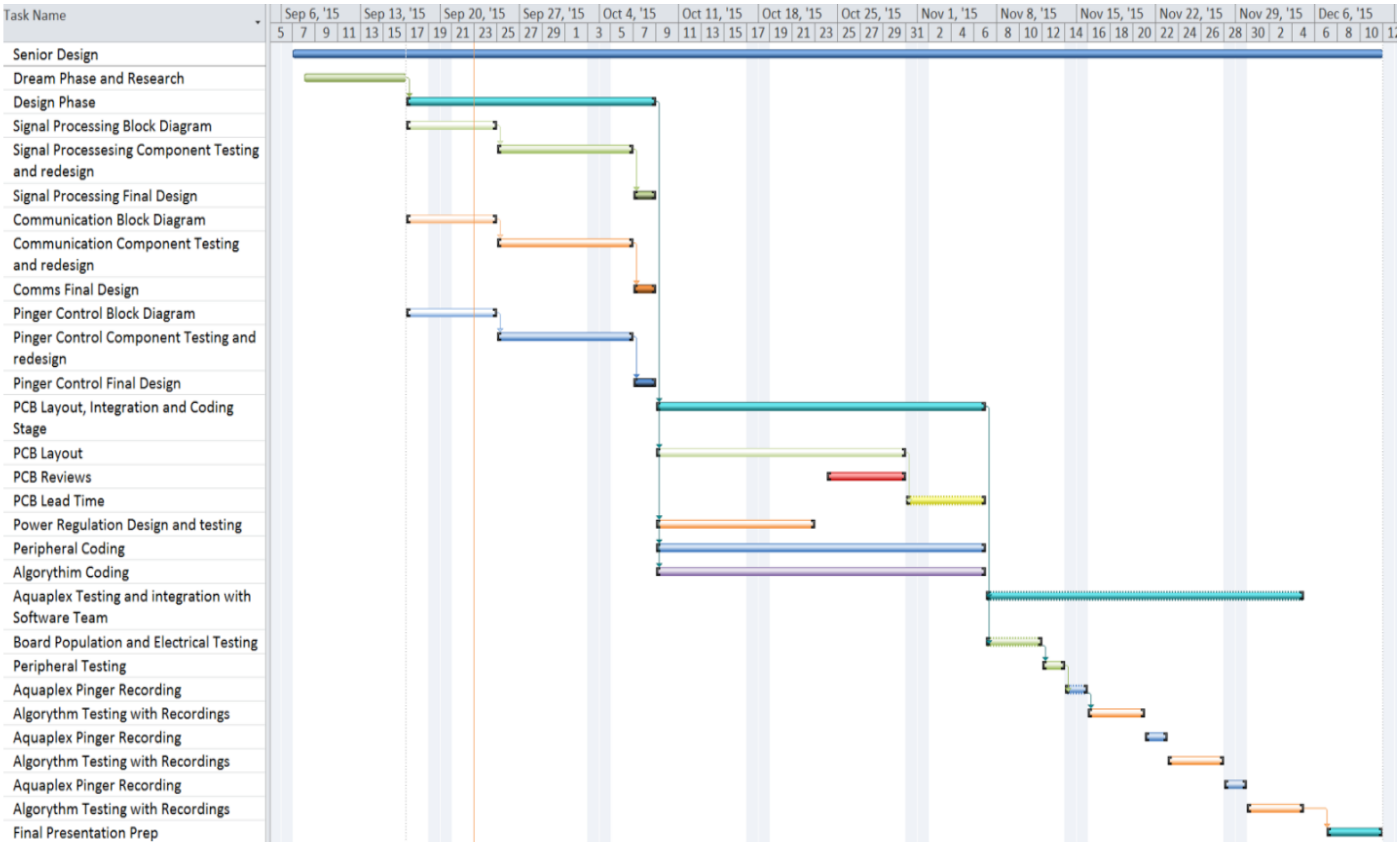

Figure 10: Software Gantt Chart

Promotional Flyer