

Design of a Small, Multi-Purpose, Autonomous Surface Vessel

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Abstract

The continued development of Unmanned Underwater Vehicles (UUVs) has also brought about new complex missions that the vehicles must perform. Such missions include mine counter measures (MCM), underwater system inspection, route surveying, and oceanographic sampling. More recently, a growing need for missions to be performed by multiple vehicles has emerged. An important task in being able to perform such a multi-vehicle operation is for each vehicle's position and orientation to be precisely known and updated to onboard sensors, in real-time, maximizing the surreptitious capabilities and quality of the data. Without this high quality navigation data, the mission performance is poor and little confidence can be given to the results.

Currently, UUVs can use inertial navigation systems, coupled with Doppler Velocity Loggers (DVLs), for navigation. However, inertial navigation systems are large, high-power, and expensive, while DVLs have limited bottom-tracking range. Some UUVs are equipped with global positioning systems (GPS), however the vehicle must surface to establish either a RF or satellite communication link. A solution, to increase the accuracy of a vehicles position is the use of a surface vessel, notably an autonomous surface vessel (ASV). One such vehicle is currently under development by the Department of Ocean Engineering at Florida Atlantic University. The ASV is being built upon an existing surface vessel navigation and control package, a vertical communication and USBL navigation system derived from the FAU-Dual Purpose Acoustic Modem and 3D motion compensation algorithm that utilizes a low cost GPS/IMU/COMPASS/ADCP system. The accurate positioning system onboard the ASV uses an acoustic uplink system between the ASV and UUVs below, to provide the UUVs with the navigation information needed for a successful mission.

The development of the ASV presents several problems such as controlling the vehicle, so that it can operate autonomously, gathering the sensor information, and passing the information to the UUVs below, in real-time. The control of the ASV can be divided into software and hardware components. On the software side, Simulink, part of Matlab, allows a user to develop a controller for the ASV by using a friendly graphical user interface (GUI). Matlab also allows for a host to target communication, either through RS-232 or TCP/IP, by using a toolbox called xPC Target. This setup allows the controller to be developed and compiled on a personal computer, the host, and then downloaded to a PC-104 stack inside the ASV, the target. Simulink blocks can also be created to control the flow of information from the sensors to the PC-104 stack, whether the sensors are connected via an AD/DA board or through serial ports using RS232 communication. While the ASV is designed to give UUVs a more accurate position without installing expensive equipment on each of the UUVs, it can also be used so that a user can monitor the progress of a mission. The communication from the user to the ASV is also accomplished using xPC Target's, host to target communication using a wireless link, and from the ASV to the UUVs using an acoustic modem. By using a surface vehicle, the mission performance of a group of UUVs can be improved by providing accurate and up-to-date positioning as well as by allowing a user to change the mission on the fly, without having to recover the UUVs.

Introduction

A limitation in the use of unmanned underwater vehicles (UUV) is their inability to receive accurate position measurements through global positioning satellites while underwater. This leads to inaccuracies when performing standard missions, such as; mine counter measures (MCM), underwater system inspection, route surveying, and oceanographic sampling. To better improve the ability for multiple UUVs to perform these tasks efficiently, each vehicle needs to know its precise location. To accomplish the task of relaying accurate position values to a non-stationary underwater vehicle the design of an autonomous surface vessel (ASV) was begun. The ASV does not limit the range or area that a UUV can operate in as this vehicle is a mobile platform that can follow the UUVs during their mission. In the development of a vehicle to accomplish this task the design processes can be separate into three parts, mechanical, electrical/hardware and software. The mechanical design of the vehicle includes the size of the vehicle, hull form and housing for the electronic components and batteries. The electrical design includes all sensors, computers, motors and batteries needed to accomplish the task at hand. The software portion of the paper does not deal with the development of a controller for the vessel, but instead focuses on using xPC Target, a software package from MathWorks, for data acquisition and vehicle control.

Mechanical Design

1- Preliminary Design

When designing the new Autonomous Surface Vessel (ASV), three major design constraints given: it would need to be relatively small, extremely stable, and be able to maintain operations for twenty-four hours at a cruise speed of 5 knots. Five hull forms were considered: catamaran, trimaran, streamlined mono-hull, troller mono-hull, and semi-submersible. In order to determine the optimal layout each of the five hull forms were quantified using thirteen design criterion based on the initial design constraints. The weighted design criterion were: sensor motion (100), volume (70), cost (50), controllability (45), ease of manufacture (40), launch and recovery (35), complexity (30), portability (25), stability (25), draft (10), drag (10), speed (10), and weight (1). The hull forms then received a multiplier for each of the thirteen design criterion that represented their efficiency. The sum of the products of the design criterion value and its multiplier would determine the overall effectiveness of a particular hull form. From this study the catamaran layout was the best with the semi-submersible as a close second.

Then, two catamaran designs were accurately studied, a small water-plane area twin hull (SWATH) design and a catamaran with a deep keel. To decide between the two hull forms it was chosen to review the two most crucial design elements, which were the hydrostatics and hydrodynamics of the ASV. The hydrodynamics of the vehicle would determine the power requirements needed to complete a twenty-four hour mission. The hydrostatics review would give an idea of the stability of the vessel. The SWATH design

had excellent hydrodynamics but in reviewing the hydrostatics the overall stability of the hull form was a concern. Large ships that make use of the SWATH design do well because they are on a scale several orders of magnitude larger than the waves they encounter. In the case of a small ASV it would not be surprising to see waves or swells that are larger than the vessel itself. From this point of view a small catamaran with a deep keel would perform better. Therefore the catamaran as seen in the artistic rendering in figure 1 was chosen because it could accomplish both of the crucial design requirements.

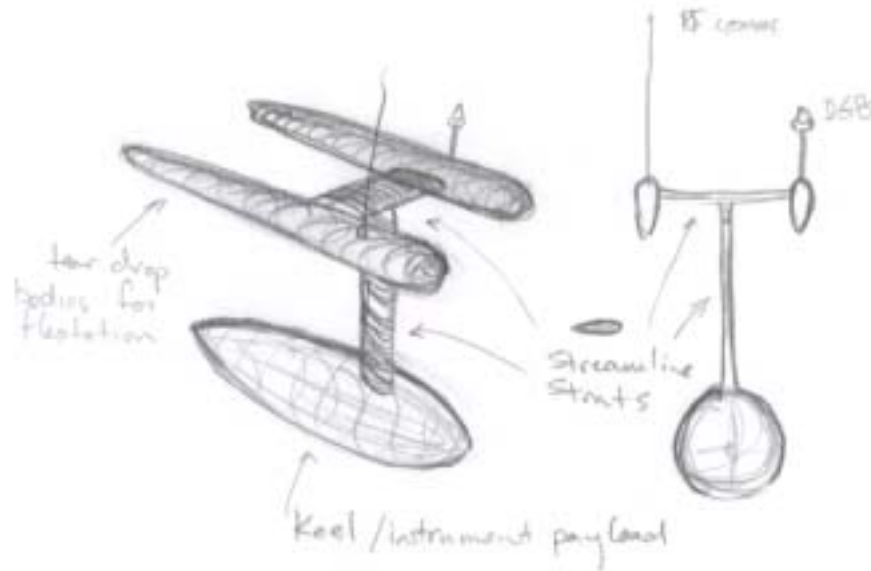


Figure 1- Initial design sketch of the proposed ASV.

2- Critical Design

a. Parametric Modeling

Once the platform layout was completed the design team needed to move forward with a more in-depth analysis of the system. This was accomplished using a parametric model of the vessel developed in MatLab. The parametric model was based on the design spiral shown in figure 2. The vessels resistance is the driving characteristic of the design spiral. Resistance for a baseline vessel is initially calculated, which is the basis of the ASV's power estimate. Using the given volumetric efficiency of the desired battery chemistry the needed volume to hold the batteries can be extrapolated from the power estimate.

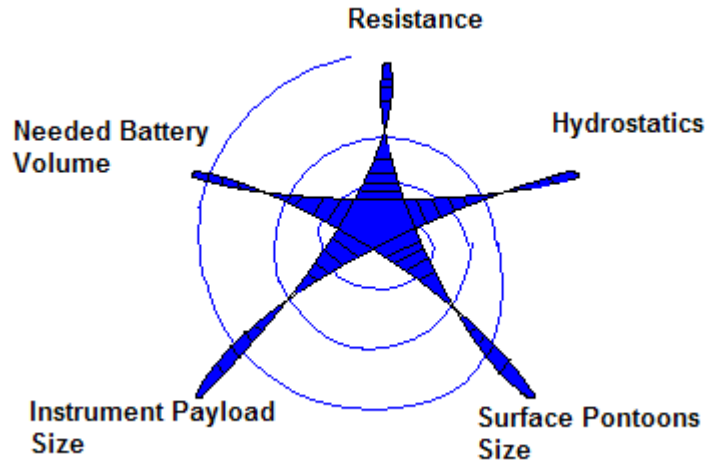


Figure 2- ASV design spiral

This volume is then used to determine the volume needed in the instrument payload (or the keel.) The size and weight of the instrument payload mandates the size of the surface pontoons. As the size of the ASV grows to accommodate the batteries needed to sustain 5 knots for twenty-four hours so does the power needed to overcome the greater resistance. This then requires that all the values be recalculated for the enlarged vessel. The hydrostatics of the ASV raps up the end of the spiral only when the ASV is positively buoyant. The relationship between weight/buoyancy and the vessel length revealed the existence of a threshold which needs to be crossed to guarantee the overall buoyancy of the ASV. The initial conditions such as battery chemistry and weight of the instrument payload were set so this threshold was around 2 meters.

After completing the topside of the vessel and including the hydrostatics in the parametric model, it was decided to split the design of the surface portion of the vessel and the instrument payload. This choice was motivated by the fact that the design of either of the two components could be completed without being dependant on the other; furthermore future payloads could be designed without the need to redesign the entire vessel. While developing the parametric model of the vessel the payload was reduced to a point load at the end of the strut and fixed at having a wet weight of 35 kg. A second parametric model was then developed for the payload where the design constraints were to align the center of gravity of the payload with the strut and an overall wet weight of 35 kg.

b. Parametric Model of Surface Vessel

Each component of the ASV was simplified into a force vector in the y-direction (vertical). The vessel being symmetric about its center (port to starboard) would further simplify the model by allowing it to be viewed as two-dimensional. The equations that determine the hydrostatics of the vessel are the sum of the forces in the y-direction and the sum of the moments about the z-axis. Three control variables were used to establish the correct attitude for the ASV *noseM*, *noseMDist*, and *goffset*. The first, *noseM*, was an added mass that would set the waterline of the vessel to its desired position. The parametric model solves the sum of the forces in the y-direction for the added mass so that a certain

percentage of the surface pontoons sit below the surface. The second variable, *noseMDist*, was the distance the added mass was from the center of the vessel. The parametric model would calculate *noseMDist* based on the sum of moments equation with respect to the forces applied on the system from weight, buoyancy, drag, and thrust. The drag and thrust forces would be taken directly from the resistance calculations within the parametric model. If the moment that was required from the added mass was greater than possible considering the length of the pontoons the model would then fix the added mass at the bow of the vessel and solve the sum of the moments with position of the payload strut, *goffset*, as the variable.

c. Parametric Model of Instrument Payload

The second model was set up to determine the added force needed to set the wet weight of the instrument payload to the design constraint of 35 kg and where a righting moment would need to be placed so the sum of the moment was zero. In this model two added forces were used to achieve the design constraints; a bow force and a stern force. It would be simpler to position the strut after the vessels wet weight was set but because there was a desired position for the strut this was not possible. In the stern there was an added buoyant force to compensate for the mass of the instruments and batteries. The strut was placed forward of mid-ship and so a weight force was needed.

d. Parametric Model Findings

The Matlab function *quiver* was used to plot the free body diagram of the parametric models as well as the moment diagram; these results can be seen in the figures 3 and 4 below.

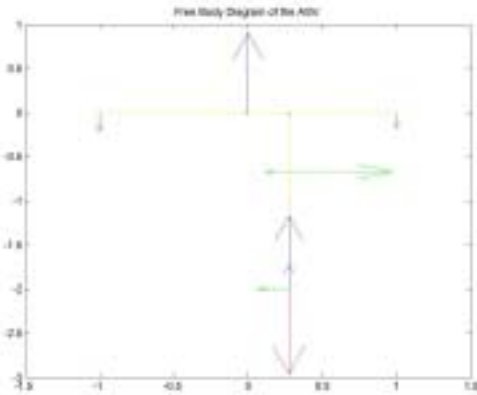


Figure 3- Free Body Diagram of surface vessel

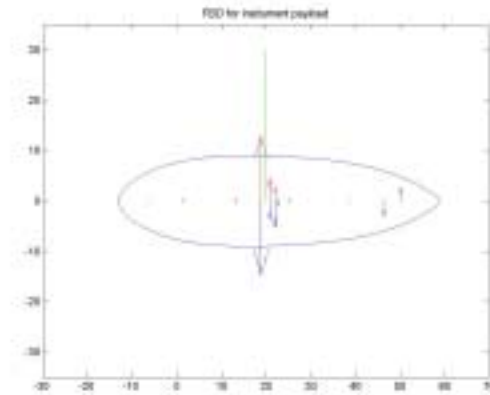


Figure 4- Free Body Diagram of instrument payload

3- Resistance

Total ship resistance is comprised of four forms of resistance frictional, wave, eddy, and air resistance. Wave and eddy resistance were combined as residual resistance and air resistance was neglected all together. The catamaran hull form was broken into three section and estimates of the two relevant resistances (residual and friction resistance) were made. At first the program was written to study the total ship resistance as a function of the length of the surface pontoons. Later the program was modified so

that the total ship resistances reflected the volume needed to store the batteries to accomplish a twenty-four hour mission at 5 knots.

a. Resistance of surface pontoons

To estimate the resistance of the surface pontoons frictional resistance was estimated using the equation:

$$R_f = \frac{1}{2} \rho U^2 S C_f C_{form}$$

C_f is the coefficient frictional resistance of a plate. The equation for C_f was found in Principals of Naval Architecture to be:

$$C_f = \frac{0.075}{\log(\text{Re}-2)^2}$$

Because C_f is the coefficient for a thin plate and the surface pontoons will not be thin plates a coefficient for hull efficiency must be used, C_{form} , which is generally within a range of 1 to 1.4. For this estimate a conservative C_{form} was used of 1.4.

The estimate of residual resistance for the surface pontoons was derived from empirical data found in Journal of Ship Research June 2001; Figure 5. The equation for residual resistance of a Wigley hull is:

$$R_f = \frac{1}{2} \rho U^2 S C_w$$

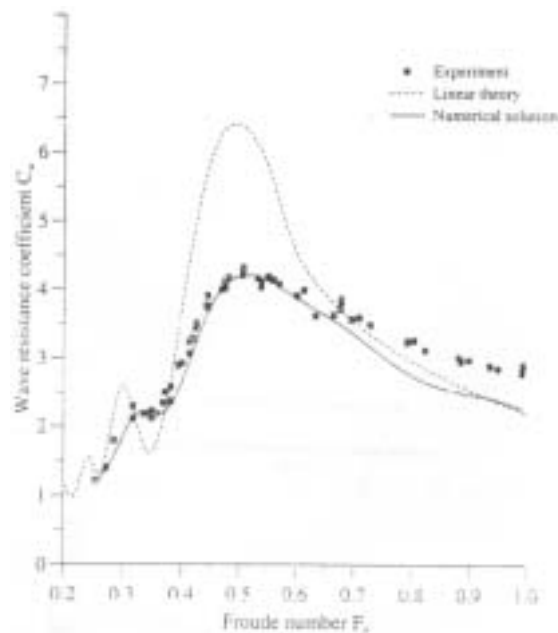


Figure 5- Wave Resistance vs. Froude number

It was suggested that for computing the resistance of the surface pontoons, given that our length to beam ratio was twenty, they should be modeled as thin plates and not as a Wigley hull. Since it would be more detrimental to error on the side of too little resistance than too much the estimate was left as it was.

b. Resistance of surface piercing strut

The frictional resistance of the strut was estimated using:

$$R_f = \frac{1}{2} \rho U^2 A C_D$$

C_D is the coefficient of drag of a streamline strut, which was taken from the fluids textbook and is based on the Reynolds number and the frontal area of the strut. The chart where the coefficient was taken from appears in figure 6.

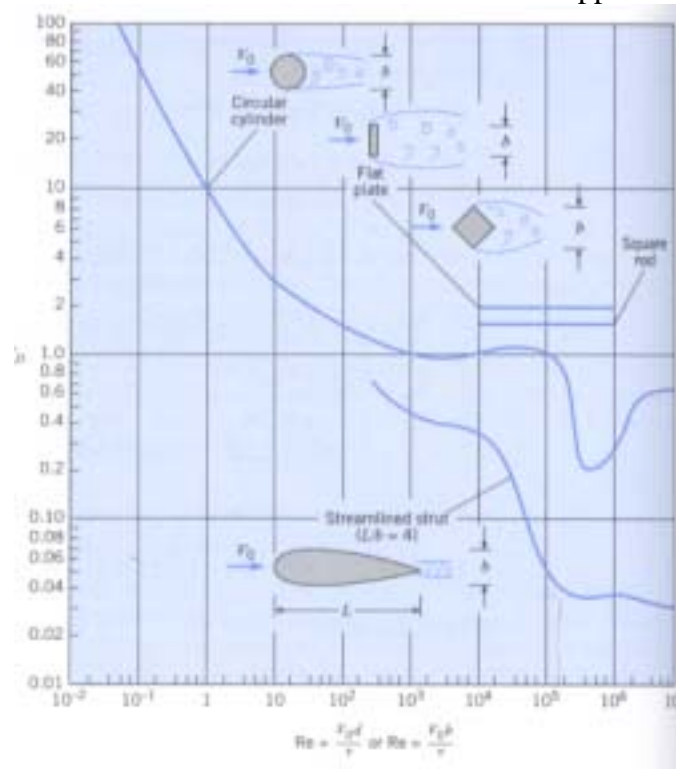


Figure 6- Resistance Coefficient for various shapes

The residual resistance for the portion of the strut that pierces the surface was calculated using:

$$R_f = \frac{1}{2} \rho U^2 d C_w$$

The term d is the diameter of the strut and C_w is the coefficient of wave resistance taken from Tuck which can be seen in figure 7.

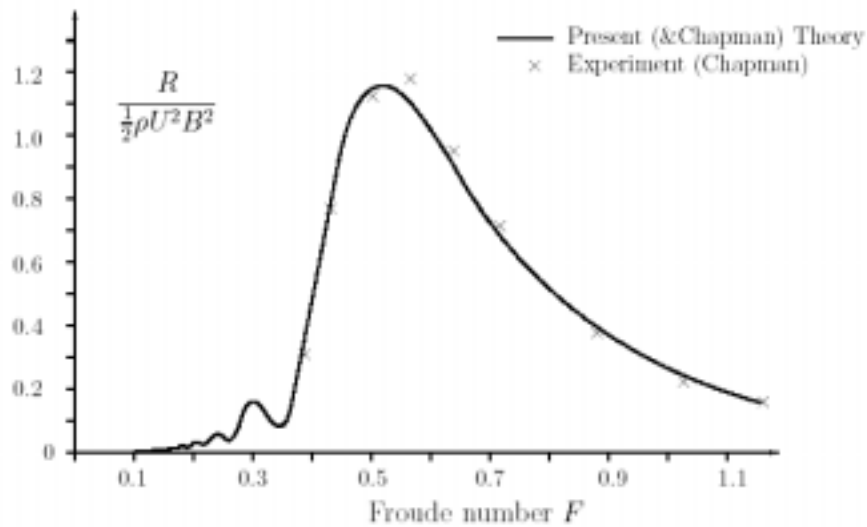


Figure 7- Resistance Coefficient for strut

c. Resistance of Instrument Payload

The shape used for the instrument payload was taken from Gertler technical documentation to minimize the friction. The friction resistance of the payload was estimated using:

$$R_f = \frac{1}{2} \rho U^2 S C_f$$

The coefficient of friction C_f was taken from Gertler technical documentation and appears in figure 8. The residual resistance for the instrument payload is neglected. There were some concerns that the depth of the submerged body was too shallow and its movement through the water would cause disturbances on the surface. According to the data provided by Gertler these effects are negligible for the given size and depth of the body.

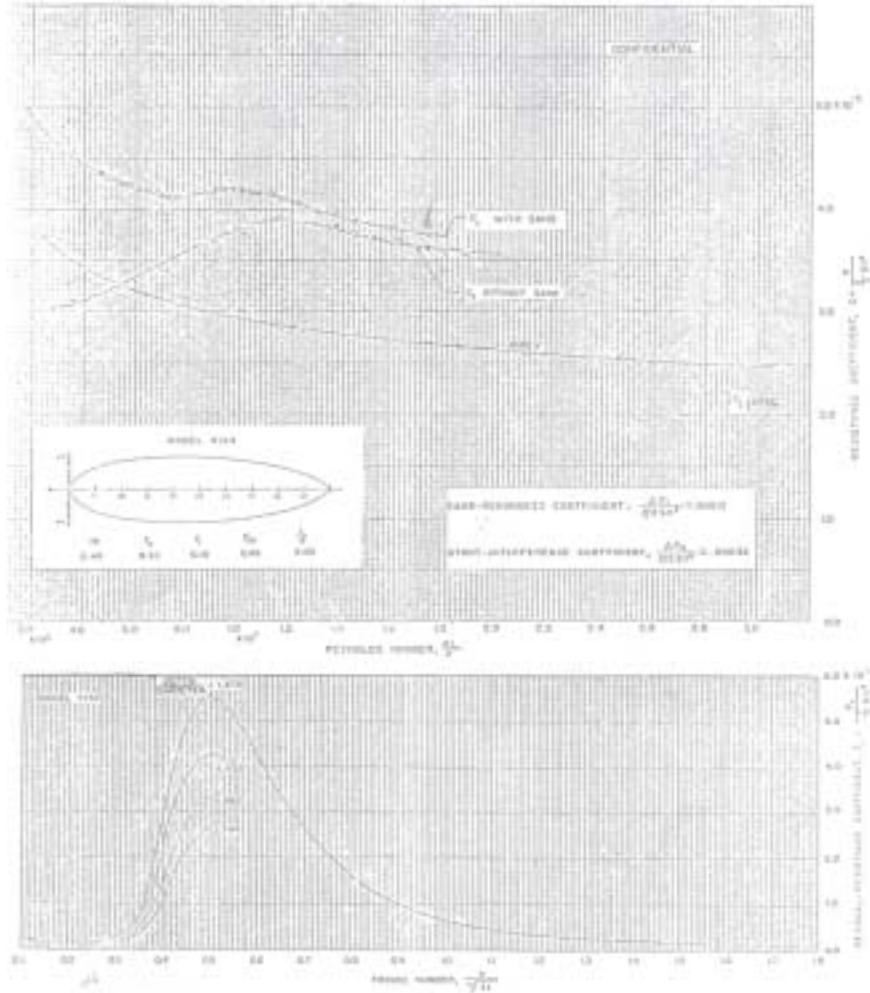


Figure 8- Coefficient of Friction for Gertler body

d. Total resistance

The total resistance of the ASV is the sum of residual resistance and frictional resistance from each of the three sections. Figure 9 shows the total resistance of the vessel and the breakdown of resistance by components. In the early planning of the layout of the vessel it was decided to make the keel double as an instrument payload. By placing the volume needed for the instruments, batteries, and computers below the surface this added residual resistance is reduced.

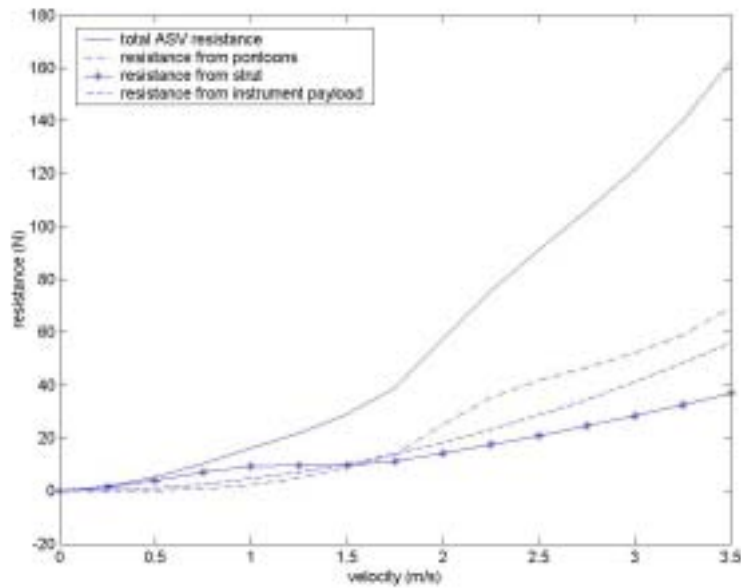


Figure 9- Resistance estimate for ASV by component

4- Structural

The structural design of the ASV was broken down into three parts: surface pontoons, strut, and instrument payload. The surface pontoons were responsible for providing the flotation for the vessel and a platform to mount the motors and communication antennas. To do this a simple foam mold poured over an aluminum frame would keep production simple and provide excellent structural support for the vessel. The strut that connects the instrument payload to the surface pontoons would need to be streamlined to reduce resistance as well as allow wires to pass between the surface and the instrument payload. The strut connects on one end to a cross brace between the pontoons on the surface while the other end attaches to the main back brace in the instrument payload. The back brace in the instrument payload would connect a series of rings that hold together the pressure vessel and the shroud.



Figure 11- ASV Model

On the surface the vessel would need a large bit of displacement to counter its overall weight. Generally boats are built with a structural shell that displaces water; the structure and displacement shell are one and the same. The shell itself is reinforced where the loads are to be expected, with stringers and bulkheads. This method has proven to work well but in terms of manufacturing it is a time consuming process. In order to avoid the problems of traditional shipbuilding an alternative design was proposed and ultimately used where the structural elements were separated from the displacement needs. An aluminum frame was assembled to provide the structural integrity of the vessel and then foam was cast around this frame for floatation. A female mold was cut in the shape of the final hull form and liquid foam was poured in around the encapsulated frame. When the mold is removed the foam hull is permanently attached to the frame. Figure 12 shows the first pontoon being cast. The first image shows the frame sitting in one half of the mold prior to the foam being poured. The second image shows the setup moments after the foam had been poured; remarkably the foam takes only a few minutes to go from liquid to fully developed foam. The final image in figure 12 shows the pontoon after it has been released from the mold.



Figure 12- The first pontoon being cast.

The frame itself is made of a combination of sheet, box, and tube aluminum. Each pontoon has a box aluminum stringer to prevent snapping of the foam pontoon where it is weakest. Because the stringer would be in the upper portion of the pontoon an

aluminum sheet was machined and welded to the stringer as a perimeter support for the foam. On the rear vertical support a plate was welded as the mounting base for the motors. The pontoons were then attached to one another with two tube aluminum braces. Schedule 80 tubing was used for its resistance to torsion. Torsion was the major concern in the cross brace because of possible torque moments that could be generated by either of the pontoons and or the strut. The cross brace will likely see torques applied to it by all three at any given time. Once the layout of the frame was established the analysis of the frame would be needed to determine wall thickness and placement of gussets for extra strength.

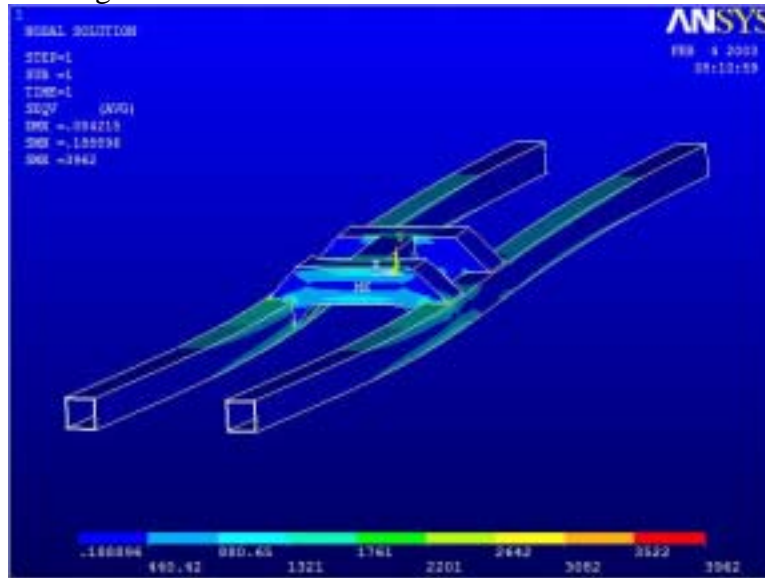


Figure 13- Frame analysis

A single strut was used to connect the surface pontoons to the submerged instrument payload. The strut would need to be strong enough to handle the mass and inertia of the payload, large enough to pass wires between the two bodies, and be as small as possible to reduce resistance. Several possible materials were studied for the makeup of the strut and in the end Chrome-moly was chosen for its superb strength. A chrome-moly's strut with the cross section seen in figure 14 having a minor axis of 1-inch, a major axis of 2.36-inches, and a wall thickness of .049 inch was chosen.

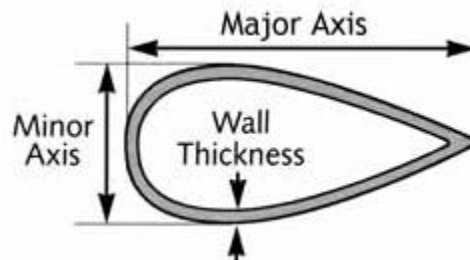


Figure 14- Cross section of chrome-moly strut.

Because of the ferrous nature of chrome-moly the strut has been powder coated to provide protection from the saltwater. The strut was studied using ANSYS for tension and torsion loadings applied to one end while the other was fixed. Figure 15 shows the results of one of these load scenarios where the maximum deflection was .0256 inches.

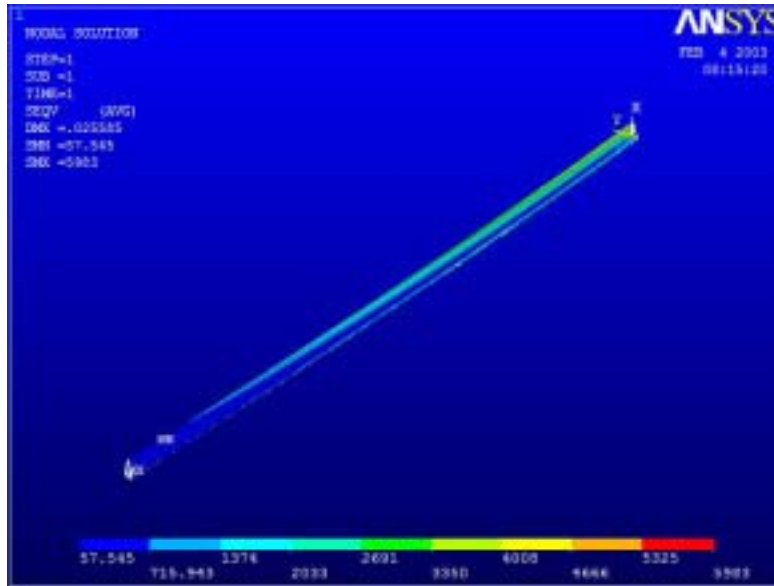


Figure 15- Results of the finite element analysis of the strut.

The brain of the ASV is located in the keel or the instrument payload. Within the confines of the streamlined shell resides a ribcage like structure that holds the computers and instruments. It was important to develop a structure that minimized shifting of these instruments with respect to one another. The two most important instruments are the Inertial Motion Unit and the Acoustic Doppler Current Profiler, which measure the change in position, velocity, and attitude of the vessel. To establish a solid base for the frame a 3/8th inch plate of aluminum was used to make the backbone. From this backbone four disks of 3/4-inch high-density polyethylene hang as a cradle for the pressure vessels holding the batteries and instruments. Running parallel to the backbone through the disks are 1/2-inch aluminum rods that increase the polar moment of inertia of the support structure. ANSYS was used to study several variations of this frame including an all aluminum version. For the analysis the frame was fixed where the strut attaches and all the loading modes started with the weights of the batteries and instruments. Several different collision cases were studied were the maximum deflection was well within the acceptable values. The chosen design was, for all practical purposes, as strong as the other proposed designs but had a lower dry weight and a lower cost. Figure 16 shows the ANSYS results of the final design.

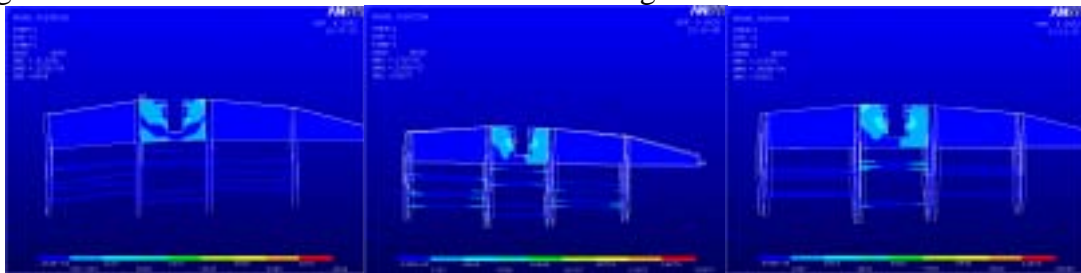


Figure 16- Results of the instrument payload frame's finite elemental analysis.

Electrical and Electronic Hardware/Systems

1- Instruments

The main purpose of the instruments is to provide the system's *State Estimator* with relevant and sufficient data for it to be able to accurately estimate the vehicle's state (position, attitude, velocity and angular velocity). They act as an interface between the ASV and its environment, providing the former with information relative to the latter.

a. Acoustic Doppler Current Profiler

The Acoustic Doppler Current Profiler (ADCP) used is a Workhorse Sentinel from *RD Instruments*. Its main role is to measure the vehicle's body fixed longitudinal, lateral and vertical velocities with respect to the sea bed. It however also provides measurements of the system's attitude, altitude, earth fixed longitudinal, lateral and vertical velocities, as well as temperature of sea water. It is located in its own pressure vessel.

This ADCP communicates directly with the onboard computer, through serial communication (RS232). Its specifications are given in **Table 1**.



Figure 17- Workhorse Sentinel ADCP

b. Compass

Measurements of the vehicle's attitude in terms of heading, pitch and roll are obtained using a TCM2 electronic compass from *Precision Navigation*. The information provided by this compass are obviously redundant with the attitude measurements from the ADCP. The *State Estimator* takes advantage of this redundancy to refine its state estimate. The electronic compass is located in the main pressure vessel.

It communicates with the onboard computer through RS232 serial communication. The specifications of this compass are given in **Table 1**.

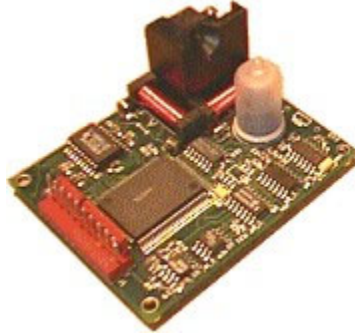


Figure 18- TCM2 Electronic Compass

c. Differential Global Positioning System Receiver

The vehicle features a Differential Global Positioning System receiver DGPS MAX, from CSI Wireless. Using the GPS satellite constellation, it provides the system with an estimate of its latitude and longitude. Those values are used by the *State Estimator*. The receiver itself is located in the main pressure vessel, while the antenna is fixed on the upper part of the vehicle, above sea surface.

It communicates with the onboard computer through RS232 serial communication. The specification of this receiver can be found in **Table 1**.



Figure 19- DGPS MAX, front and back, antenna

d. Inertial Measurement Unit

The Inertial Measurement Unit (IMU) used on the vehicle is a MotionPak form BEI Electronics. It outputs measurements of the vehicle's longitudinal, lateral and vertical acceleration, as well as its angular velocity in heading, pitch and roll. It is located in the main pressure vessel.

On the contrary of the three aforementioned instruments whose outputs are digital, the MotionPak generates analog signals. Those signals are filtered by a bank of DP68 Low-Pass Filters from Frequency Devices. The filtered signals are then fed to the analog to digital converter (3- c.), and are then available to the *State Estimator*. The specification of the MotionPak and the filters are presented in **Table 1**.

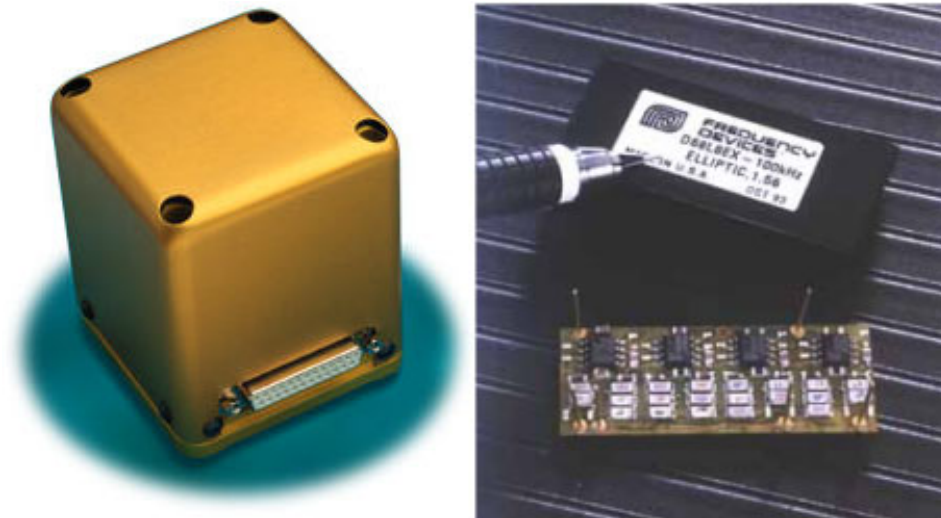


Figure 20- MotionPak and DP68 Filter

e. Acoustic System

The vehicle is equipped with an acoustic system, whose purpose is to communicate with an Autonomous Underwater Vehicle (AUV). This acoustic system is constituted of a pair of transducers used for transmission and reception, an array of transducers in Ultra Short Base Line (USBL) configuration, and a Dual Purpose Acoustic Modem (DAPM) developed at Florida Atlantic University (FAU). The DPAM uses a transmit transducer and a receive hydrophone to communicate with an AUV, while the USBL array is used to determine the relative position of the AUV the vehicle is communicating with.

The DPAM is connected to the onboard computer through RS232 serial communication.

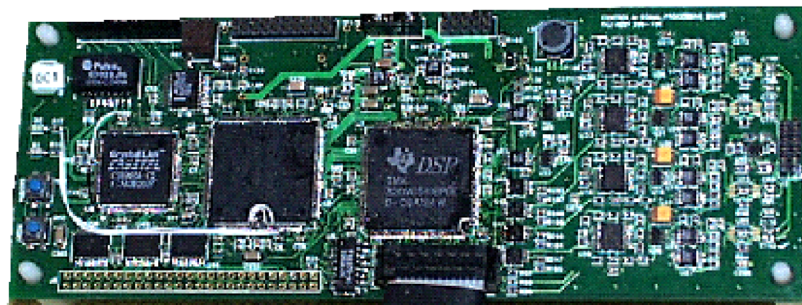


Figure 21- Dual Purpose Acoustic Modem

The vehicle is equipped with a total of five instruments: Acoustic Doppler Current Profiler, electronic compass, Differential Global Positioning System receiver, Inertial Measurement Unit and acoustic system. The data provided by those sensors include the

vehicle's position, attitude, velocity, angular velocity and acceleration, which are all used by the *State Estimator*. In addition, the acoustic system provides the surface craft with a mean of communication with an AUV, as well as the relative position of this AUV.

ADCP Workhorse Sentinel 300 KHz		TCM2 Electronic Compass		
Velocity Range	± 5 m/s default ± 20 m/s maximum	Heading Accuracy when Level	0.5°	
Ping Rate	> 2 Hz	Heading Accuracy when Tilted	1°	
Standard Deviation	As low as 20 mm/s	Heading Resolution	0.1°	
Minimum Depth	As low as 4 m	Heading Repeatability	0.1°	
Maximum Depth	Up to 120 m			
DGPS MAX		Tilt Accuracy	0.2°	
Horizontal Accuracy	< 1.2 m	Tilt Resolution	0.1°	
Maximum Position Update Rate	5 Hz	Tilt Repeatability	0.2°	
		Tilt Range	$\pm 27^\circ$	
Low Pass Filters DP68		Sampling Rate	Up to 8 Hz	
Transfer Function	8 poles, 6 zeros, elliptic	IMU MotionPak	Rate Channels	Acceleration Channels
DC Voltage Gain	± 0.1 DB maximum ± 0.05 DB typical	Standard Range	$\pm 50^\circ/s$	± 1 g
Stop Band Attenuation Rate	80 DB minimum	Scale Factor Calibration	$< 1\%$	$< 1\%$
Cut Off Frequency		Scale Factor Temperature	$< 0.03\%/^\circ C$	$< 0.03\%/^\circ C$
Stability	$\pm 0.01\%/^\circ C$	Bandwidth	DC to > 60 Hz	DC to > 100 Hz
Amplitude	-0.035 DB			
Phase	-325.5°			
Phase Match	$0 \rightarrow 0.8$ fr $\pm 2^\circ$ max $\pm 1^\circ$ typical	Temperature Sensitivity	$< \pm 3^\circ/s$ from $22^\circ C$	$< 100 \mu g/^\circ C$
		Long Term Stability	$< 0.2^\circ/s$	$< 500 \mu g$

	<i>typical</i> <i>0.8->1 fr ± 4°</i> <i>max ±</i> <i>2° typical</i>	G Sensitivity	< 0.02°/g	N/A
Amplitude Accuracy	<i>0->0.8 fr ±0.2DB</i> <i>max</i> <i>±0.1DB</i> <i>typ.</i> <i>0.8->1 fr ±0.3DB</i> <i>max</i> <i>±0.15DB</i> <i>typ.</i>	Linearity	< 0.05% of full range	< 20 μg/g ²

Table 1- Instruments Specifications

2- Actuators

The propulsion system of the vehicle consists of a pair of trolling motors.

a. Motors

The motors used are Riptide trolling motors, from Minn Kota. They can use up to 900 watts of power. Providing them with about 10% of that amount should prove sufficient to reach a decent cruise speed.

The two motors are located port and starboard, at the back of the vehicle. In this configuration, steering the vehicle is achieved by setting different RPM on each motor. Steering is further facilitated in our case by the fact that the motors can rotate a full 360°.



Figure 22- Minn Kota Riptide trolling motor

b. Motors Control

In the retail state of Riptide motor, the RPM of the motor and its orientation are controlled by a foot pedal. We obviously had to modify this setup.

The motor is now controlled by a High Performance Standard Node (HPSN). A HPSN is classically used as a node in a Lonwork network, but we took advantage of its capacity to generate digital and analog signals to control the motors. Each motor is controlled by a HPSN, which is located in a pressure vessel above sea surface. To further enhance the propulsion system, we implemented a compass on each motor axis, which measures the relative orientation of the motor with respect to the vehicle. Those compasses are Vector Electronic Modules, from Precision Navigation.

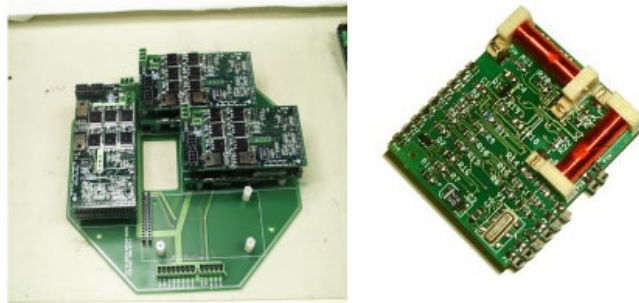


Figure 23- HPSNs and Vector Electronic Module

3- Computer

The choice of the type of onboard computer was strongly influenced by the embedded nature of the system. The onboard electronics had to be compact enough and feature a reasonably low power consumption. For those reasons, we chose for the onboard computer to be of PC104 format, one of the most commonly used standards for embedded system. Not only does this format satisfy the aforementioned criteria, but the fact that it is widely used makes it easy to find any type of board, featuring any functionality one might need.

The onboard computer is constituted of several boards: a MOPSlcd6 computer, an Emerald-MM serial hub, a Diamond-MM-32-AT Analog to Digital and Digital to Analog (AD/DA) converter, and a HE104 Direct Current to Direct Current (DC/DC) converter. All of which is located in the main pressure vessel.

a. CPU Board

The CPU board is a MOPSlcd6 from JUMPtec with a CPU clock speed of 166 MHz. It features two serial ports, a parallel port, an Ethernet access, and supports both a keyboard and a VGA screen. It has a flash disk memory from SunDisk with a capacity of 32 Megs. The CPU board is of PC104 format.

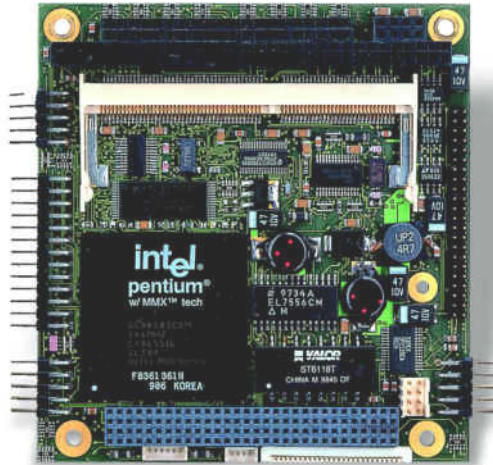


Figure 24- CPU Board MOPSLcd6

a. Serial Hub

We had to use RS232 serial communication between the computer on one side, and the ADCP, the DGPS, the compass and the acoustic system on the other. The CPU board, however, only has two serial ports. We thus had to use a serial hub. The serial hub we chose is the Emerald-MM, from Diamond Systems. Featuring four ports, it brings the computer's total number of serial ports to six. The serial hub is of PC104 format.

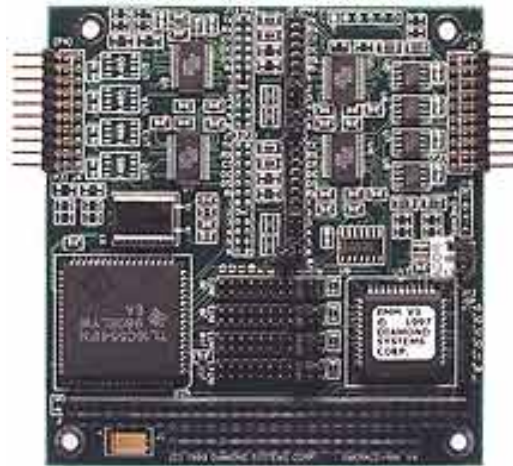


Figure 25- Serial Hub Emerald-MM

b. AD / DA Converter

The IMU's data format being analog, we needed an analog to digital converter. The AD/DA converter board is a Diamond-MM-32-AT. It can be configured to either have 16 differential channels, 32 non-differential channels, or 8 differential and 16 non-differential. This flexibility was desirable since the MotionPak output is differential, but we wanted to still have the capacity to read

2- Signals and Communication

a. Host / Target Communication

The computer described in 3- is the target in the host/target framework of *xPCTarget*. Communication between host and target is essential. Even though the target could run autonomously by taking advantage of *xPCTarget* embedded option, we still want the host to have a certain degree of control over the target. Indeed, the host can be used to start or stop the mission, reboot the target, monitor the application running on the target and tune this application on the fly. All these functionalities are a necessity during the testing process of the system, and will still be useful in the future. For the host to be able to communicate with the target without the hindrance of a cable, we chose to use a BreezeNet PRO.11 Series wireless Transmission Control Protocol / Internet Protocol (TCP/IP) system, from Alvarion. Communication between host and target are allowed for up to a 50 Km distance.

This system is composed of a pair of transmitters / receivers, or access points, one connected to the host, the other to the target. The target's access point is located in the main pressure vessel, and its antenna is mounted on the upper part of the vehicle, above the sea surface.



Figure 28- Wireless TCP/IP Access Point BreezeNet PRO.11 Series

b. Instruments / Computer Interactions

As mentioned in 1-, most of the instruments connected to the onboard computer are using RS232 serial communication. This type of communication is numerical and allows the computer and the connected instrument to interact using strings of characters. For the application running on the target to be able to properly initialize the instruments and collect data from them, serial drivers had to be written. Indeed, *xPCTarget* does not really support any instrument per se, but, through a RS232 library, it enables the creation of processes controlling the computer serial ports, and thus enables communication with any device using RS232 communication.

Using this library, we wrote a serial driver for the ADCP, electronic compass, DGPS and acoustic system.

On the other hand, the IMU's output data are of analog format. As mentioned earlier, we use a Diamond-MM-32-AT AD/DA converter to transform these analog signals into numerical signals useable by the computer. *XPCTarget* supports the Diamond-MM-32-AT, meaning that it features a driver enabling the CPU board to interact with it. However, this driver is not taking full advantage of

the possibilities of the Diamond-MM-32-AT. In particular, it does not allow the user to configure the converter such that it has 8 differential and 16 non-differential inputs (**3- c.**). To be able to fully take advantage of the capacities of this board, the pre-existing driver was modified.

c. Actuators / Computer Interactions

The HPSNs controlling the motors (**2- b.**) are connected to the onboard computer's parallel port.

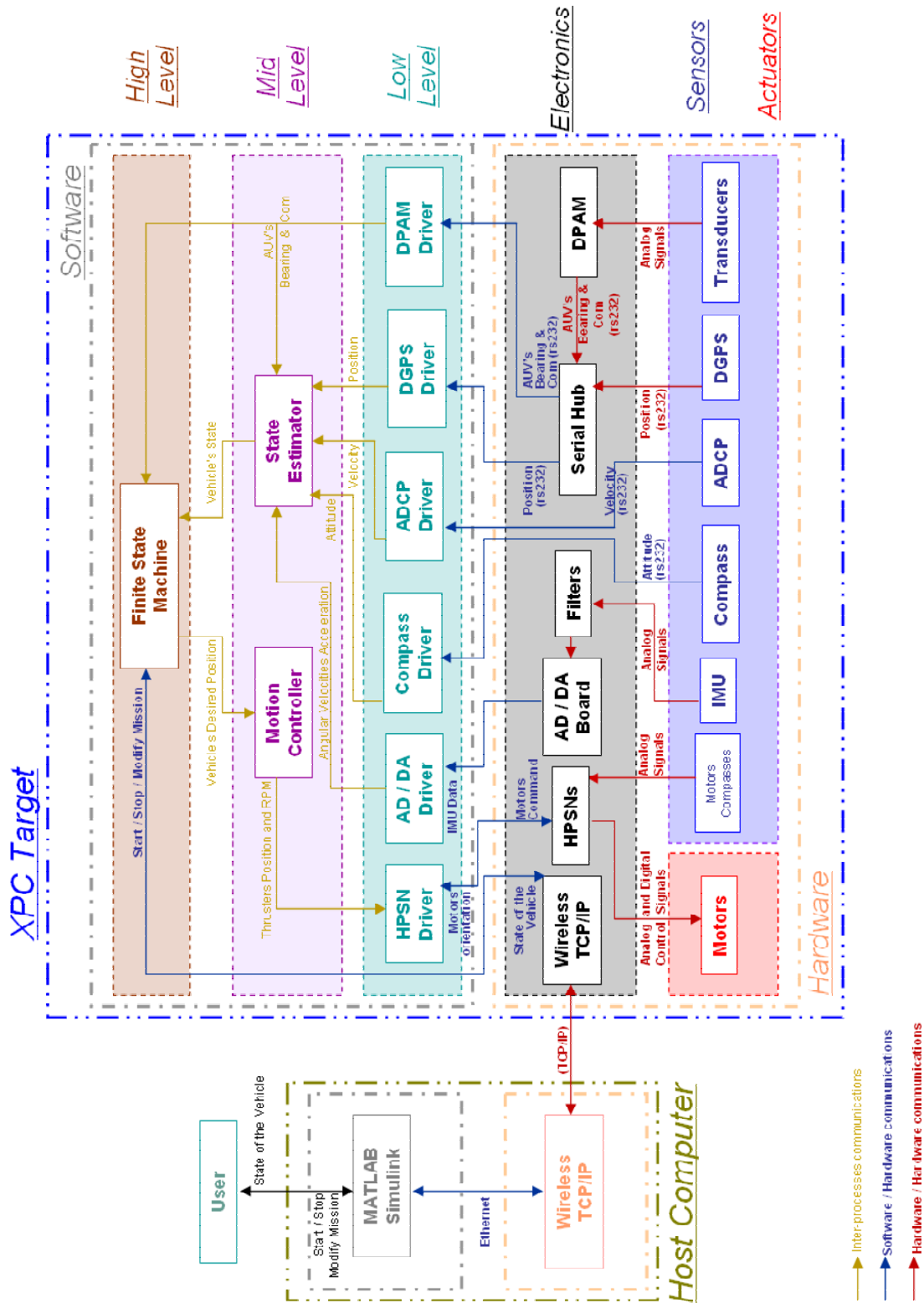


Figure 29- System's Signals Block Diagram

3- Power

a. Batteries

The vehicle is powered up by six pairs of 12 volts batteries (the used output voltage being $12V \times 2 = 24V$). The batteries we use are the lead acid NP12-12 from Yuasa. Each of them provides 12Ah, which implies a total of 1728 Wh. The batteries are located in their own pressure vessel, below sea surface.



Figure 30- Yuasa Battery

b. DC / DC Converters

The batteries provide unregulated 24 volts, and the onboard computer's DC/DC converter (**3- d.**) can supply 5, 12, -5 and -12 volts regulated. However, several instruments and electronic systems need to be supplied with a specific voltage not available from either the batteries or the aforementioned DC/DC converter. In particular, the IMU (**1- d.**) needs ± 15 volts, and both the DPAM (**1- e.**) and the ADCP (**1- a.**) require an input voltage higher than 24 volts to work satisfactorily. We thus had to integrate two extra DC/DC converters to the system.

The ± 15 volts regulated is supplied by a BWR A Series DC/DC converter, from Datel. It accepts an input voltage from 18 to 36 volts, has a typical efficiency of 84%, and can output up to 15 watts.



Figure 31- Datel BWR A Series DC/DC Converters

The power for the DPAM and the ADCP is provided by a DC/DC Converter Module from Vicor. It can use an input voltage that ranges from 18 to 36 volts, has a typical efficiency of 87%, can output 100 watts and has a 48 volts regulated output.



Figure 32- Vicor DC/DC Converter

These two DC/DC converters were chosen not only for their high efficiency but also for their compact packaging. The Datel converter is 1 x 2 x 0.48 inches, and the Vicor is 2.28 x 1.45 x 0.5 inches. Both of them are located in the main pressure vessel.

c. Power Distribution

The power distribution on the presented vehicle is simple. The batteries supply unregulated 24 volts. On one side the motors use the raw (unregulated) 24 volts and on the other side the 24 volts is converted to the various voltages utilized by the sensors and electronic systems.

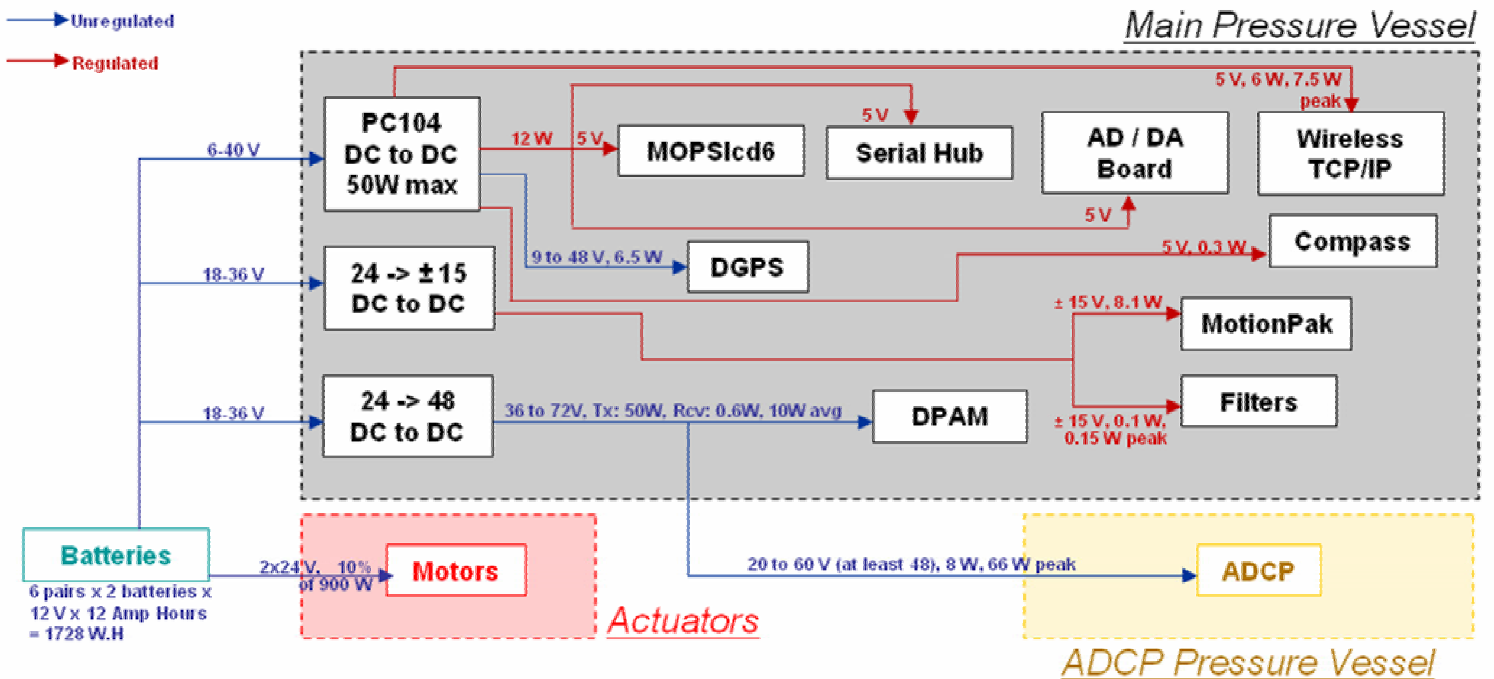


Figure 33- Power Distribution Block Diagram

Software: xPC Target

1- Background Information

A recent addition to Math Works', MatLab software is xPC Target. This toolbox is designed to allow a user to run code based on Simulink, another Matlab toolbox. Simulink can be used to create simulations, develop control systems and/or data acquisition. To accomplish this task, xPC Target is based on a host and target configuration. In this configuration the host has the full version of MatLab installed while the target does not. Instead the target is "booted up" using a low level kernel that has been created using the host machine. This allows the target to connect to the host, download and then run the code created on the host machine. The graphical user interface (GUI), that Simulink is based upon allows for the easy development and implementation of control and data acquisition systems. The GUI interface can cause a decrease in the design and debugging time, enabling the engineer to produce a quality product, faster.

2- Target Kernel

Traditionally, systems such as autonomous vehicles are controlled by C code, or some such language, running on a computer which has a traditional operating system (OS), like QNX. xPC Target eliminates the need for an OS, instead loading a kernel created by Matlab on the target machine. The target computer loads this kernel from a floppy drive or local hard drive. The boot disk can be created in Matlab by typing the following command at the command prompt, "xpcsetup". This opens the window shown in **figure 34**, allowing the user to define the compiler path, host/target communication protocol, and other pertinent information.

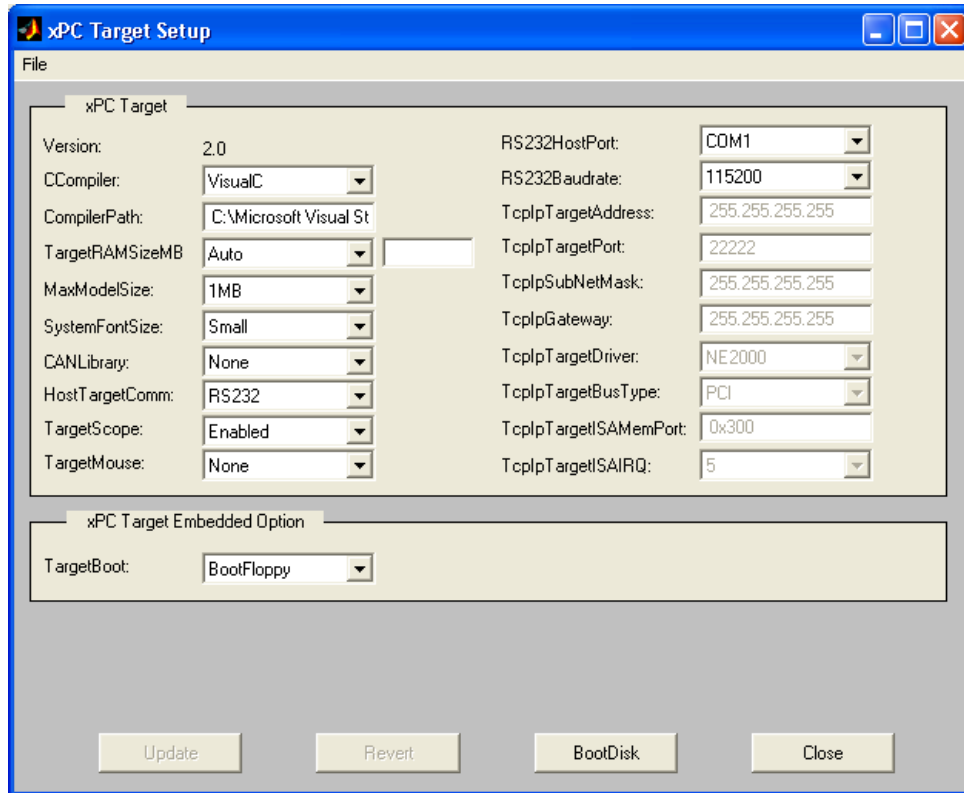


Figure 34- Creating target boot disk

3- Hardware Support

The first major issue when beginning the design process of a system that is to be controlled using Simulink and xPC Target is hardware selection. Since xPC Target is a relatively new system, the driver support for various hardware is limited. This adds a new dimension to the selection process since, the hardware, as with any system, must be chosen to meet the objectives of the project, but now must also be supported by xPC Target. A quick check to see what pieces of hardware are currently supported by xPC Target can be accomplished by seeing if there is a “block” for that item in Simulink. This can be accomplished by, opening the “Simulink Library Browser” and searching through the xPC Target blocks. For example if one wants a list of Analogue to Digital boards that are supported by xPC Target then the steps needed to be taken would be, to open the “Simulink Library Browser,” then “xPC Target” and finally “A/D.” This can be seen in **figure 35**. However, one thing to note is that, not all of the analogue to digital boards produced by, these companies, are supported. For example for Diamond Systems, only the MM-32 and the MM are supported, whereas Diamond produces several analogue to digital boards, including the MM-16, the Ruby-MM and the Ruby-MM-1612. While blocks could be developed to act as drivers for a piece of hardware this is a very time consuming process. In fact, in the process of designing this ASV drivers had to be developed for a serial hub which was needed to allow data to flow between the PC-104 stack and all of the sensors in use on the vehicle.

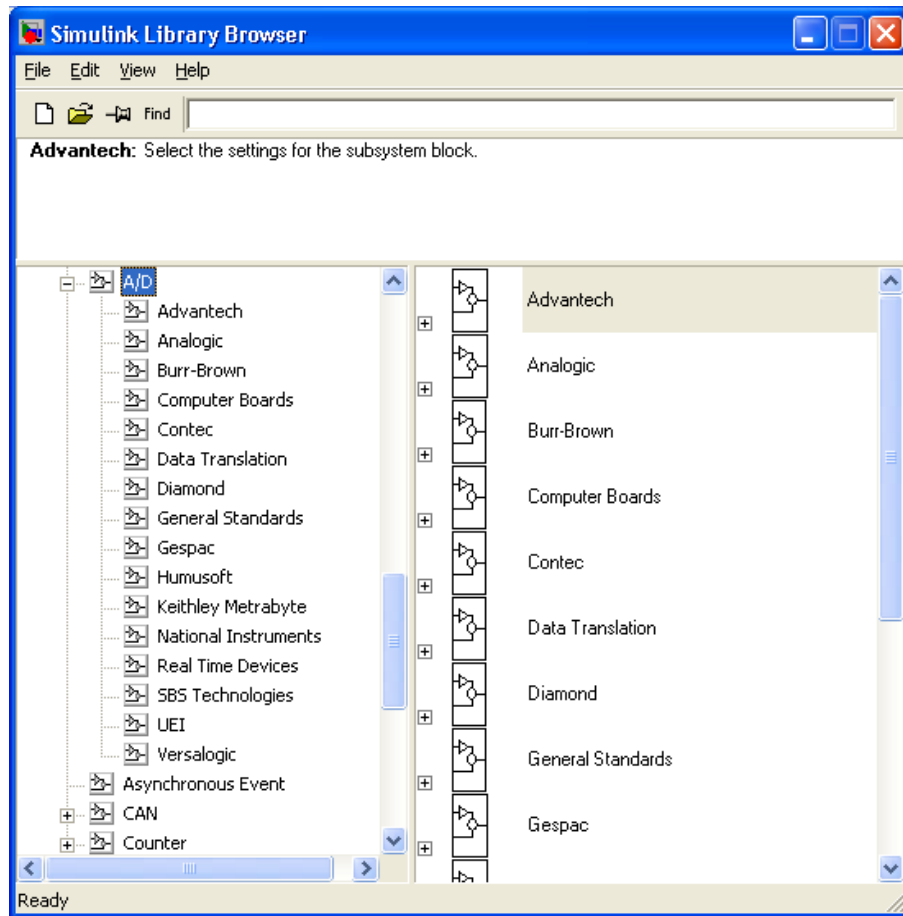


Figure 35- Driver blocks for various A to D boards

4- I/O

The xPC Target toolbox allows for the connection of sensors to the target computer. To accomplish this task xPC Target has been provided with drivers for various Analogue to Digital boards, as mentioned above, serial ports (RS232), as well as I/O ports, read and write blocks. For the ASV currently under development sensors will be connected through and A to D board and serial ports as shown in **Figure 35**. Driver blocks are available so that two serial ports can be used on the target. However, for this application more than two serial ports were needed. To overcome this obstacle the code for the RS232 Setup blocks was modified allowing the use of four serial ports on the target computer. The number of A to D channels was not limited by software, but instead by the physical A to D board.

5- S-functions

While many devices are supported by xPC Target, all devices are not supported. The S-function block allows the user to define their own Simulink block. This can be used in I/O driver applications, such as allowing for the use of four serial ports, or for use with specific hardware items. When using various sensors such as a DVL or ADCP, C code can be written to communicate with the device and parse incoming data. This C code is then incorporated into the Simulink block diagram through an S-function block. S-functions do not necessarily have to be written in C, but can also be written in C++,

Fortran, Ada, or as a Matlab m-file. When incorporating S-functions into a block diagram Matlab's compiler can be used, or Matlab can use another compiler, such as Microsoft Visual C++, to compile the code. An unlinked S-function block can be seen in **figure 36** and **figure 37** shows an S-function block linked to code used for communication and parsing of data from a Doppler Velocity Logger (DVL).

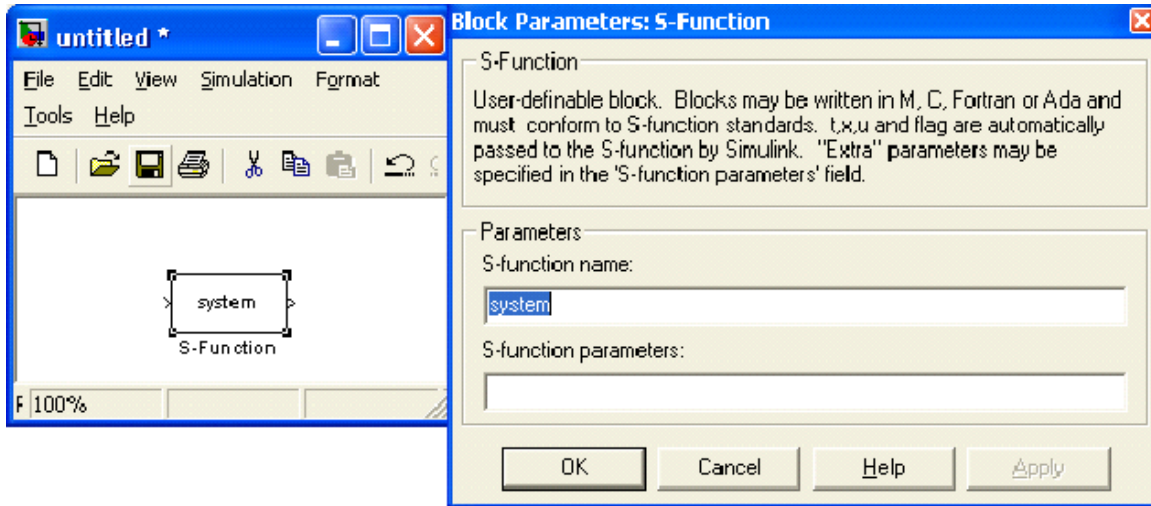


Figure 36- S-function block

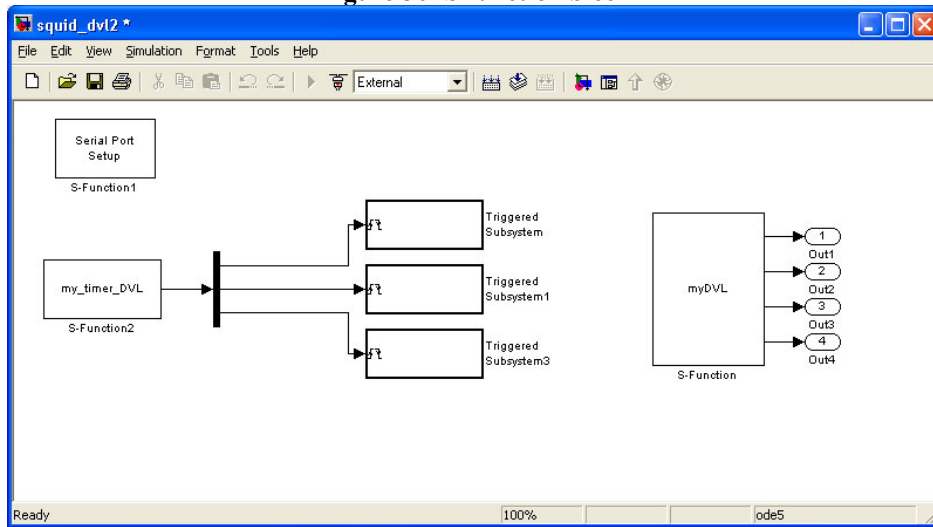


Figure 37 Linked S-function blocks

6- Host/Target Communication

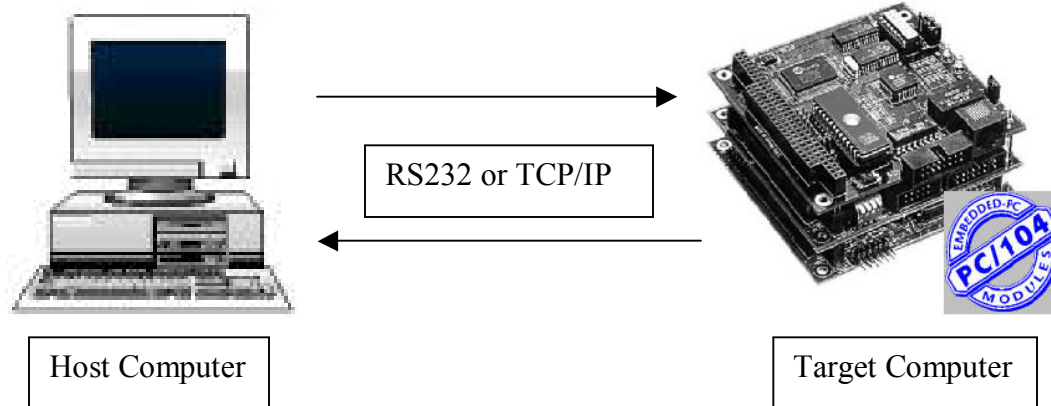


Figure 38- Host/Target communication protocols

The communication between the host and target is a key component of xPC Target. The host must be able to download the compiled code, created from the Simulink block diagrams, to the target. Although, once the compiled code has been downloaded to the target, communication with the host is not necessary, although its presence enables several important features. The features including logging data to the host's hard drive, monitoring signals and the ability to change certain parameters without stopping the code. With xPC Target the host to target communication can be accomplished using either RS-232 or TCP/IP protocol.

a. Communication Protocol

When using the TCP/IP protocol the host and target can be connected computer to computer or via a network. It is important to note that when using the network the target must have an IP address which cannot be assigned to the computer through the xPC Target kernel. The IP address for the target can be created by loading a standard operating system, such as QNX on the target and then following the normal procedure for that OS. The target's address must also be entered into the xPCTargetAddress field found in the xPC Target Setup window. The xPC Target Setup window can be opened by typing the following command, 'xpcsetup' at the command prompt. If the user chooses to use the RS-232, (serial) connection then the target does not need an IP address as it can only be connected computer to computer. As with any such connection a null modem must be used in this configuration. Since xPC Target does not support more than four serial channels the RS-232 connection might not be appropriate, depending on the number of sensors that have to use a serial port to connect to the target.

b. Command Interfaces

The communication between the host and target is used not only to download the developed block diagrams, but also to change parameter values in the block diagrams, monitor signals on the target and to log data to the hard drive on the host. These tasks can be accomplished, from the host machine, using two

different interfaces found in Matlab. The two interfaces are the Web Browser Interface and the Custom Dials and Gauges. Of these two interfaces, the web browser is the most versatile. When using this interface the host must first be disconnected from the target. This can be accomplished by typing “xpcwwenable” at Matlab command prompt. A web browser, such as Internet Explorer or Netscape is then used to connect to the target, using the target’s IP address. Once connected to the target, scopes can be added or subtracted to signals, certain parameters can be changed, and there is a limited data logging capability. The data logging is limited because the signals cannot be logged on the host in real time and can only be uploaded after the target application has been stopped. The amount of data is also limited to the size of the RAM on the target computer. A screenshot of this interface connected to a target can be seen in **figure 39**. The Custom Dials and Gauges Interface allows the user to add and subtract scopes to the various signals in the target application. The data logging capabilities of this interface are the same as for the Web Browser Interface. **Figure 40** is a screen shot of the Custom Dials and Gauges Interface.

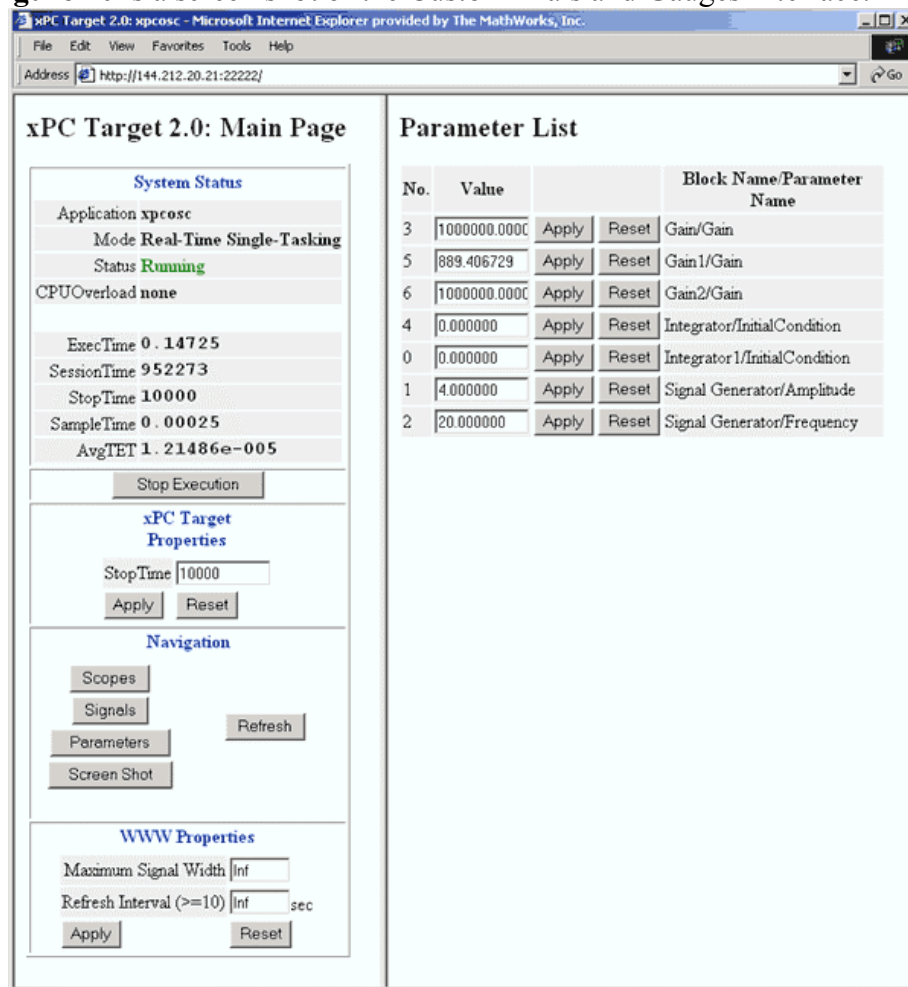


Figure 39- Web Browser Interface

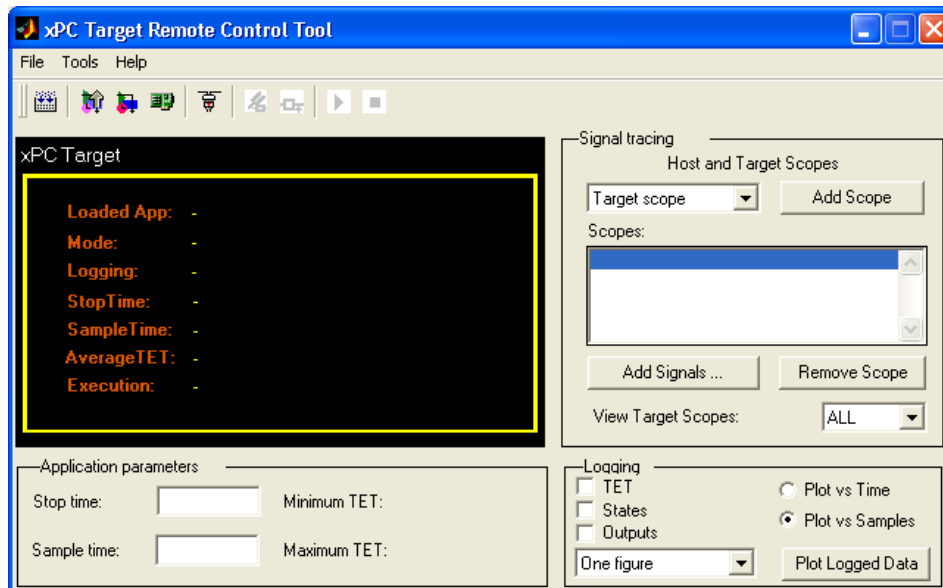


Figure 40- Target Interface

c. Data Logging

Data logging is necessary if the user wishes to view information obtained from sensors, while the target application is running. This information could describe the state of the system, such as heading and velocity, or the data could describe the conditions surrounding the vehicle, such as temperature and pressure. While it has been stated that the target does not need to communicate with the host once the compiled code has been download to it, this connection is currently necessary for data logging. Unfortunately the current version of xPC Target (2.0) does not allow data to be logged to a hard drive on the target. Data can be saved to the memory on the target and uploaded to the host after the target application has completed, but this does not provide enough space for significant data logging. Currently the only way to avoid this limitation on the amount of data that can be logged is to log the data to the host's hard drive. This requires a connection between the host and target. The process of logging data to the host's hard drive is fairly simple. The steps needed to log data are:

- 1) Tag the signal so that it can be exported from the target to the host, this is accomplished by typing "xPCTarget = label_name;" into the "Description" field found in the "Signal Properties" window, this is shown in **figure 41**;
- 2) After the block diagram has been downloaded to the target at the command prompt type "xpcsliface('model_name')" this causes a new Simulink window to open that has "From xPC Target" blocks that are linked to the tagged signals;
- 3) To log or view the data add "Save to Workspace", "Display", or "Scope" blocks to the "From xPC Target" blocks.

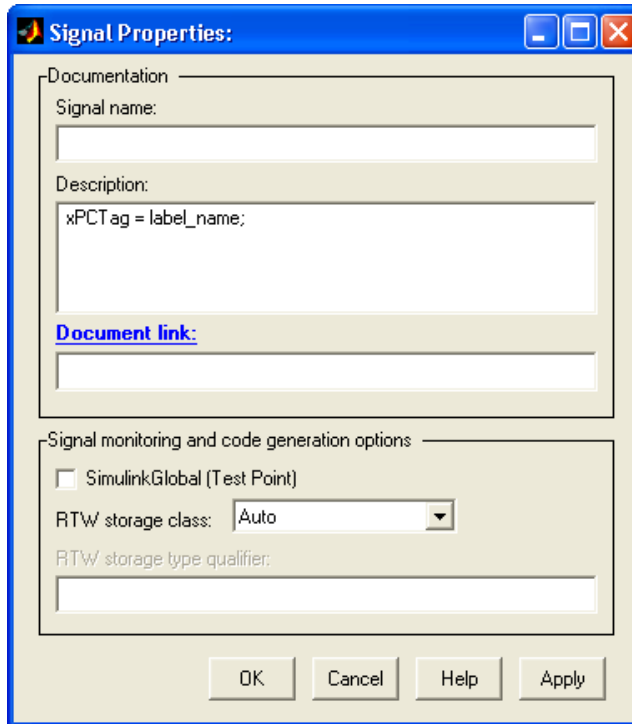


Figure 41- Labeling signal to export to the host computer

This dependence on a connection between the host and the target leads to another obstacle when dealing with a non-stationary target. However, this can be overcome by using a wireless Ethernet connection. The system would now be able to move freely while maintaining communication between the host and the target, although the target's range would be limited to the range of the wireless link.

Conclusion

This autonomous surface vessel (ASV) was designed with the ability to accurately know its own position and then use this information so that multiple, unmanned underwater vehicles (UUV) could better know their position. This ability will allow for better underwater tracking, resulting in more accurate and efficient search patterns. Currently for most UUV's to get a fix on its position they must interrupt their search pattern, rise to the surface and receive their position via global positioning satellites. While this would not pose a problem in an ideal environment, in the ocean this can lead to large errors in position due to drift from ocean currents and/or waves. By enabling the UUV to continuously update its position based on the information relayed to it from the ASV via an acoustic modem, the vehicle can continue search patterns and mark objects of interest with much higher accuracy and efficiency. The ASV can also provide a communications link between the user and a UUV. This communication link could potentially be used to modify the mission of the vehicle without having to perform a time costly recovery and re-launching of the vehicle. To prove how the use of an autonomous surface vessel can increase the efficiency of the deployment of unmanned underwater vehicles testing will be conducted in July of 2003.