

A 3D, FORWARD-LOOKING, PHASED ARRAY, OBSTACLE AVOIDANCE SONAR FOR AUTONOMOUS UNDERWATER VEHICLES

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Abstract

Autonomous underwater vehicle platforms currently lack a robust sonar system for forward-looking obstacle avoidance, detection, and navigation. Existing sonar systems (even forward looking systems) generally do not provide depth information ahead of the vessel in a navigationally effective manner. Additionally, these sonar systems generally do not provide navigation commands/suggestions to control systems for use in avoiding obstacles ahead of the vessel autonomously.

FarSounder's technology is capable of providing 3D depth information ahead of a vessel for a large field of view with a fast update rate. Currently, this technology is being commercialized as a human user interactive forward-looking navigation tool for surface ships. FarSounder believes that this technology can be effectively adapted to become an innovative AUV navigation aid providing autonomous decision making aimed at enabling the AUV to effectively detect, classify, localize, and navigate.

The objective of our effort is to develop a 3D forward-looking, collision avoidance sonar for undersea guidance and control in shallow water. Results from FarSounder's 3D forward-looking surface ship sonar will be presented along with FarSounder's proposed "black box" solution for AUV navigation and control.

Introduction

The most basic and important piece of marine navigation information for both the manned and unmanned vehicle is water depth information ahead of the vessel. The most common method for water depth relies on historical depth information in the form of charts. Due to navigation error, data gaps, survey errors, dynamic changes of the sea floor and the presence of transient inwater obstacles such as

shipping containers, buoys, logs, other vessels and whales, historical charts are often unable to prevent collisions and groundings.

Over the past 15 years, there have been a variety of products billed as Forward-Looking Sonars (FLS) and Obstacle Avoidance Sonars (OAS). These products have been developed in an effort to avert the cost of billions of dollars in damage and lost time due to groundings and collisions. Unfortunately, all the commercial FLS and OAS systems fall short of the ultimate goal: to provide 3D depth information in real-time for a large field-of-view with a quick update rate in a navigationally effective format.

Most of these systems are based on a series of 1D or 2D pings which are then sewn together to form a 2D or 3D image over time. The 1D based systems are generally capable of building a single 2D slice with a series of 1D pings although some products are simply 1D echosounders angled forwards. Some products take as long as 90 seconds to build a single 2D slice. Even worse, some of these systems build their image by mechanically scanning their transducers in order to gather data at various angles. These FLS systems cannot deliver range, bearing AND depth information to the user. Only two of these three dimensions can be provided over time.

Because of a combination of their 1D or 2D scanning techniques and beam resolutions, typical FLS systems are only capable of operating at short ranges when in shallow water. In shallow water, they are limited by their water depth performance. Some systems can only provide range and bearing to targets ahead of the vessel. By definition, the bottom (an acoustic target) is present at all ranges at all bearings in shallow water. In this case, these systems alert the user of danger everywhere, because they cannot distinguish the "safe" sea-floor from the

“dangerous” inwater target or protruding obstacle.

Apart from their performance drawbacks, when applied to Unmanned Underwater Vehicles (UUVs), commercial surface ship navigation sonars are generally found to be too big, require too much power, or rely on human readable user interfaces. Those systems specifically adapted for UUVs and which have attempted to help solve the shallow water navigation problem, have generally been found to be custom solutions. In many cases, these have turned out to be expensive, time intensive systems which require intimate integration and coordination with the rest of the vehicle’s navigation and control systems.

UUVs often use a suite of navigation sensors such as inertial navigation systems, GPS, altimeters, pressure gauges, base line acoustic positioning devices and speed logs. These instruments typically operate independent of the UUV platform and provide streams of data to the UUV’s central navigation/mission controller. This central controller then typically uses all of the available inputs combined with dead reckoning to determine its next navigation/propulsion command.

The independence of the individual sensors enables the flexibility of using a single type of sensor on a wide variety of platforms. Separating the operation of the sensor from the control software/system improves the entire platform’s stability and reduces the control system’s complexity allowing fast development and flexible configuration. Additionally, by creating a generic sensor solution that is appropriate for a wide variety of platforms and applications, the market demand and user experience drive fast improvements in performance along with size and cost reductions. The UUV community could benefit greatly from a generalized FLS solution.

FarSounder has developed a generalized FLS solution for manned surface ships and envisions the development of such a UUV product. Surface ship sonar systems can be a useful tool and model for developing a UUV level product. Many of the problems encountered in surface ship navigation are also found in UUV applications.

Current Surface Ship Technology

FarSounder is currently selling its FS-3 forward-looking sonar product. It is based on the 5 generations of hardware technology that has been developed over the past 6 years. The

technology that the company has developed is capable of producing a true 3D image with a single ping. Unlike other FLS systems which require multiple pings to build a large field-of-view, the FS-3 creates a 90° field-of-view image with a single ping, providing the user range, bearing, *and* depth information. The operating ranges for various target types are shown in Table 1.

Target Type (Target Strength)	Maximum Detection Range
Shipping Container (8 dB)	1000'
Whale (4 dB)	700'-900'
Navigation Buoy (0 dB)	600'

Table 1: FS-3 maximum detection ranges for various target types

The FS-3 operates at a center frequency of 60 kHz and is capable of operating on platforms at up to 10 knots. Future software updates are expected increase the maximum operating speed to 20 knots. The sonar head utilizes phased array processing and consists of 96 receive channels. On board roll and tilt sensors are used to stabilize the sonar image up to +/-20° in both axis. The sonar head is a network based unit which communicates via Ethernet to one or more user interface computers running FarSounder’s SonaSoft™ processing and Graphical User Interface (GUI) software.

The processor component of the software is a comprised of a Windows™ DLL which handles FarSounder’s patent pending target model based processing. The processing DLL is part of the entire user interface software package. However, because of its modularity, it could be reused in an embedded application. It is currently being optimized to for Intel’s™ SIMD™ compatible family of processors.

FarSounder’s processing technique utilizes a 2-dimensional receiver array and goes beyond traditional beamformer processing by adding an additional stage of processing called target models. A simplified diagram of the receive signal flow is shown in Figure 1a. These target models are able to intelligently extract information from the beamformed data and produce image outputs of much higher quality than are normally achieved with traditional processing. The product of the target models is an increase in the effective resolution of the array. By improving the effective resolution of the receive array, FarSounder’s processing

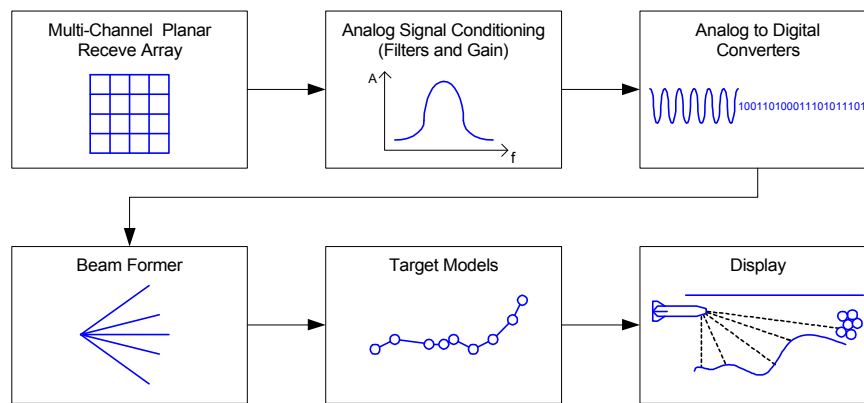


Figure 1a: Receive signal processing flow

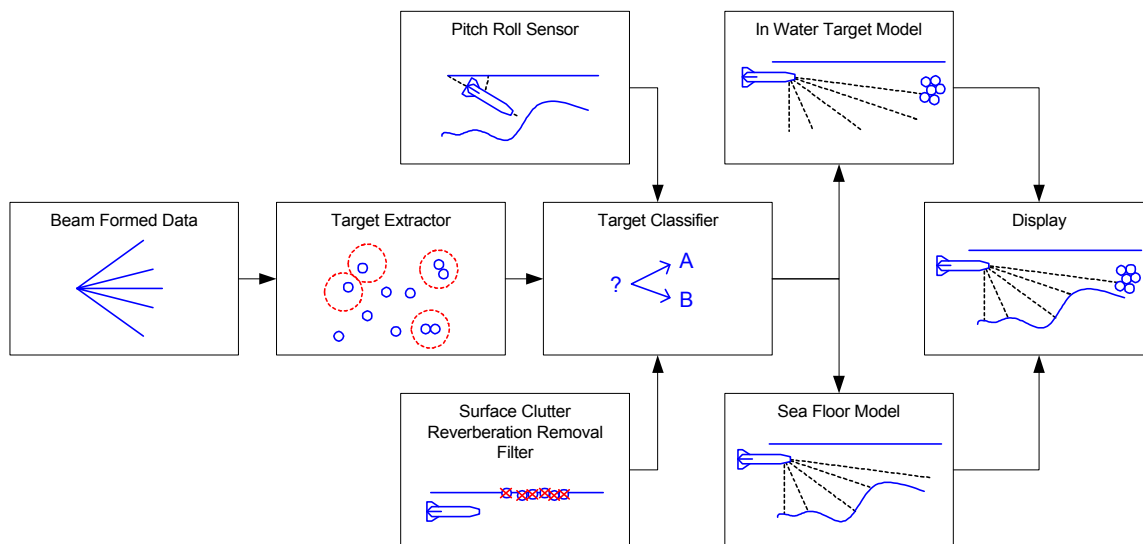


Figure 1b: Target model components expanded

technique is capable of achieving much higher Water Depth performance than what is traditionally achieved from an array of a given aperture. For targets within the system's Water Depth capability, depth measurement is possible. The target models also allow for the processing and detection of obstacles beyond the system's Water Depth capability.

The target modeling process that FarSounder has developed is key in enabling the 3D capability of the FLS system. Figure 1b is a flow diagram of the Target Model's components. Basically, the Target Model begins by intelligently extracting potential targets from the beamformed data. A series of classification routines separate the potential targets into two different categories for further processing. The classifier also uses roll and pitch information in order to stabilize the target environment aiding the classification process. Like radar systems, a 3D FLS will receive echoes from both waves as the air-water interface and the bubbles created by wave action.

The amount of surface clutter rejection can be specified by the user and targets fitting these criteria are removed at the classification stage. Like standard marine radars, smaller targets at the surface will be lost as the wave action increases. Unlike these radars, the target model allows for the detection of targets below the surface even when the surface clutter obscures surface targets. This is particularly useful for subsurface navigation.

Currently, the two categories of classification are sea floors and in-water targets. Once classified, the potential targets are processed differently depending upon into what type of target category they are grouped. These processing stages include noise rejection, sidelobe rejection, and image processing. Once processed, the target model outputs are ready for display. Currently, the display drawing technique is different for these two categories. The sea floor targets are surfaced, while the in-water targets are drawn as blob groups as shown in the following figures.

The FS-3 is currently specified as an 8 Water Depth sonar. It is capable of consistently producing depth maps to a range equal to 8 times the depth of water below the system. Often, water depth performance of 12-20 Water Depths are achieved under some conditions. Figure 2 is an example of a real-time, single ping image where an in water target (Quonset Point's Pier 2 in the Narragansett Bay) is detected and plotted at ranges well beyond the system's Water Depth capability.

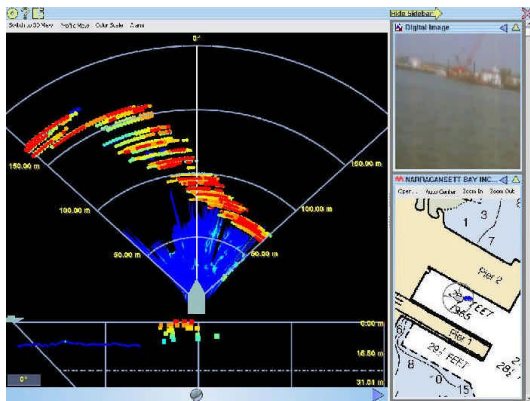


Figure 2: In-water targets detected at beyond bottom mapping range.

In the figure above, the 3D FLS data is shown in large left hand window. In this case, the data is plotted with an orthographic projection with the view point from directly above. The color is mapped to depth, where red is shallow and blue is deep. The data can also be plotted in a 3D perspective image as shown in Figure 3.

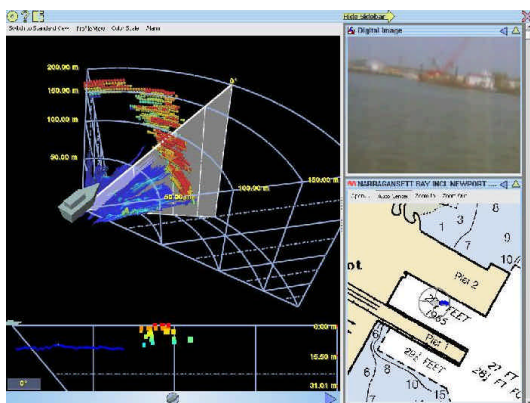


Figure 3: Pier wall in 3D perspective plot.

In both figures, a Profile Slice is shown in the bottom portion of the sonar display window. The Profile Slice is the bathymetric profile ahead of the vessel along the white Profile Selector plane. In both images, the Profile Selector is pointed directly ahead. The user can arbitrarily select the angle for the profile selector.

The data set shown in these two figures is one example of a shallow water environment in which UUVs may have missions. Being able to accurately detect the pier wall separate from the sea floor could be important in mission navigation and planning. Other data set examples of environments in which UUVs may operate are shown in Figures 4 and 5.

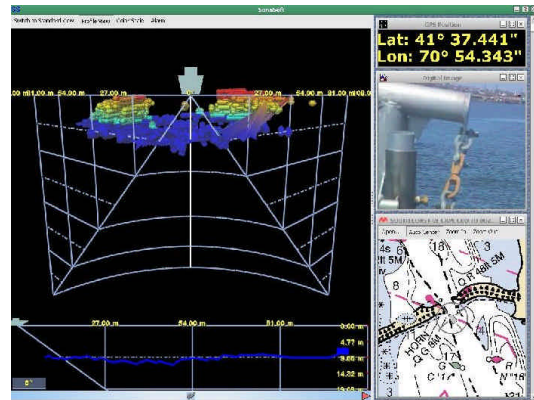


Figure 4: Passing between the walls of a hurricane barrier.

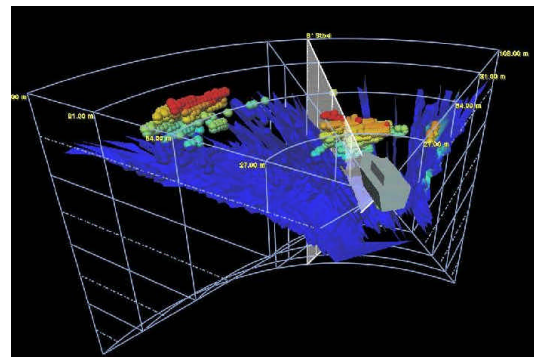


Figure 5: Two bridge pilings from the Narragansett Bay.

In Figure 4, the image is an example of the vessel passing through a hurricane barrier. As the emphasis on port security in local harbors and the use of UUVs for military operations in foreign waters increases, including the passage through a port barrier such as this may become a more likely part of a UUVs mission.

Figure 5 shows an example of two large bridge pilings coming out of a relatively flat sea bottom. UUVs used in scientific or survey applications may encounter environments such as this. Missions in these areas may include circling around the pilings as part of a bridge scour study or perimeter patrol of important assets such as the Brooklyn Bridge in New York.

Development and Alterations Needed for Deployment Aboard UUVs

Today's FarSounder product consists of 3 components: the Sonar Head, the Power Module, and the User Interface software. The Sonar Head consists of a 10 inch diameter array face with a 7 inch diameter pressure case attached behind the array face as shown in Figure 6a. It contains both the transmit and receive transducers (Figure 6b), data collection electronics, (Figure 6c) and roll and tilt sensors for image stabilization. The entire package is approximately 14 inches long and is accessed via an underwater, wet matable connector.



Figure 6a: FarSounder's FS-3 sonar head.

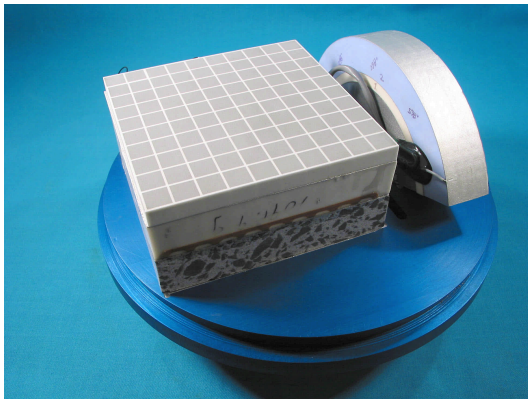


Figure 6b: FS-3 transducers.

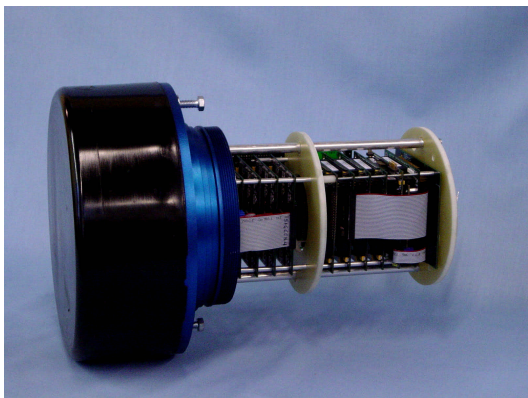


Figure 6c: FS-3 data collection electronics.

The Power Module is a 2U rack mountable component. It contains the arbitrary waveform, signal generator circuitry used to produce the transmit signal, power amplifier circuitry used for amplifying the transmit signal, and the power supplies for the Sonar Head electronics. A single cable connects the Power Module to the Sonar Head. A standard RJ-45 connector allows the Power Module to connect to a standard Ethernet network for connection to the User Interface software and a standard AC power input supplies the power.

The User Interface is a software package designed to operate on a Windows XP™ platform. The software package has been designed with ease of development in mind. A central application (the "App") handles data management, window placement, user interface graphics and layout and, multi-threading support. The App is capable of dynamically loading and managing a number of DLL modules which are used for all hardware specific, processing specific and data display specific processes. Because of the inherent flexibility designed into the App, different modules can be developed for different data processing applications, different hardware interactions and different display outputs. This enables developers to quickly develop new components with minimal platform stability risk and minimal infrastructure redundancies and inefficiencies.

Some of system's components or portions thereof are currently appropriate for UUV applications. The Sonar Head and the processing algorithms found in the software can be readily incorporated into a UUV system. Albeit, the current Sonar Head size and power requirements would exclude many small UUVs. These two components are also the most complex and value added components of the system. The other components could be quickly replaced with UUV appropriate systems. These modifications include: a UUV appropriate Power Module, the development of a software control interface appropriate for embedded applications, and porting the processing code from the Windows XP™ platform to the embedded operating system of choice. Additionally, a smaller, lower power sonar head should be developed for smaller UUV applications.

The major changes for the Power Module are size reduction, power consumption reduction, DC power operable, and a packaging redesign. Plans for developing a class D amplifier system are currently underway which will easily enable these changes. Additionally, the power module

electronics may be combined with the Sonar Head electronics allowing a single pressure case to enclose all the system's electronics.

Because the processing code can be reused with minimal porting, the software development required for the UUV version of the sonar is relatively straight forward and easy to implement. Aside from the platform porting, a simple, easy to use, machine readable interface will need to be developed. This can be achieved easily using current program and hardware communication techniques. The software interface to be developed is described in further detail in the following section. Because there will no longer be a need for a dedicated user interface computer, the processing component will be moved to an embedded system. Again, this system could be added to the single pressure case of the combined Sonar Head/Power Module.

Proposed UUV Solution

FarSounder has the objective of developing a FLS for UUV applications. The goals of this objective are: to produce a prototype system with footprint and power consumption suitable for an unmanned vehicle platform, to produce a programming interface (API) to be used in integrating sonar into existing unmanned vehicle packages either through software connections or digital communication methods, and to demonstrate the prototype with navigation decision making using an UUV. The sonar system to be developed should be small, navigationally effective, and flexible for use on a multitude of platforms.

The proposed system will consist of 2 components: a modified Sonar Head and a software interface. The Modified sonar head will house the receive and transmit transducers, the receive electronics, the sonar processing core and the transmit electronics in one combined pressure case. Using FarSounder's existing hardware, this pressure case may only be suitable for larger UUVs. Size and power reductions will be achieved with FarSounder's planned next generation data collection system and will enable the technology to be installed on smaller UUVs.

There will be two simple connections to the Sonar Head's pressure case: a DC power connection plug and a communications plug. The DC power connection plug will allow system integrators to supply power to the sonar system. Since many UUVs have a power control system, the Sonar Head will have an unregulated power input connection. It will also provide a regulated input for ease in system integration at the cost of power efficiency.

The communications plug will enable both RS-232 and Ethernet connections. RS-232 is a serial communication protocol developed in the 1960's which is still widely used today. An RS-232 interface will be provided to allow for integration into low level control systems. Ethernet is a newer serial protocol which allows greater flexibility and data throughput. It will be provided to enable the users to take the most advantage of the sonar system.

A simple, low data rate packet communication system will be developed to provide an interface to the sonar. In its most basic form, the navigation control system will be able to query the sonar systems as to the depth and range to targets at various bearings. The sonar head will also be capable of sending alarm notifications based on user defined parameters without navigation system queries. A detailed API will be provided for the system integrator. This will allow the FLS to be used as just another "black box" as shown in Figure 7. Additionally, the complete raw data from the receiver system can be uploaded via Ethernet to an off UUV control station for further analysis or real-time human display. This option may only be viable for Remote Operated Vehicles (ROV) or during tethered testing of autonomous systems.

The system to be developed will be based upon FarSounder's current FS-3 product. In an effort to make the hardware as small and low power as possible, a new set of performance capabilities have been specified. These performance values have been developed with the understanding that the UUV mission requirements are often different than the surface ship requirements. These performance values are shown in Table 2 and can be modified to fulfill specific UUV requirements.

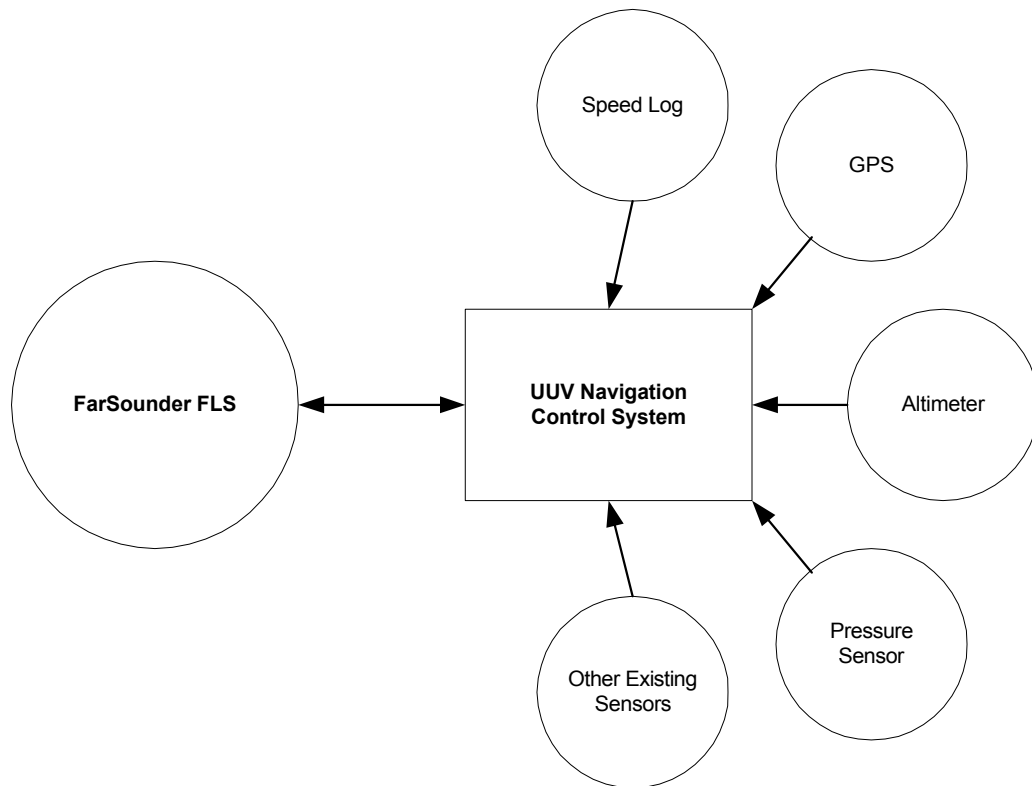


Figure 7: FLS as part of a complete UUV control system

Maximum Range	50m
Water Depth Performance	12-20
Field-of-View	90°
Transmit Source Level	200 dB
Center Frequency	100 kHz
Receive Channels	48
Resolution	12.5° (v) x 16° (h)
Effective Resolution	4.5° (v) x 8° (h)
Accuracy	2° x 2°
Ping Rate	Up to 1 Hz
Power Consumption	15 Watts
Volume	700 in ³
Maximum Operating Speed	10 knots

Table 2: Proposed UUV sonar performance specifications

Conclusion

The UUV community could benefit greatly from the improvements that have, in recent year, been made in surface ship sonar technology. FLS sonar has the ability to improve situational navigation by providing real-time depth information relative to a UUV.

For the FLS to be come an effective part of a UUV's navigation suite, development is needed to create a sonar system that is not designed specifically for the vehicle and mission. FarSounder proposes to create a "black box" system based on its FS-3 product. This FLS system would be capable of interfacing with a wide range of UUV control systems and would allow for quick integration.

There are no major hurdles precluding the adaptation of FarSounder's existing product to a UUV suitable product. Minor software development will be required long with repackaging the electronics.