

Deep Ocean Survey and Search Using Synthetic Aperture Sonar

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Abstract-Deep ocean towed surveying is an ideal application for synthetic aperture sonar (SAS). The towed platforms move slowly to maintain operational depth. Operational frequencies are necessarily low to provide adequate coverage range, yet the desire for improved resolution at range demands longer arrays.

A new 60kHz SAS system employing a three stave interferometric swath bathymetry component is presented. The bathymetric data are analyzed for performance and compared with International Hydrographic Organization (IHO) standards. Explanations of an optional Synthetic Aperture Interferometric Bathymetry processing package are undertaken showing increased data density which by filtering to produce a decimated set provides lower apparent noise from multiple scatterers.

Low frequency, high resolution SAS systems will have area coverage rates comparable to conventional sidescan sonars but will provide resolution that is hard to match, even with the highest frequency survey grade conventional sidescans. A brief discussion examines some benefits of SAS in this regard.

Recent surveys for buried cables and wreck searches have revealed the benefits of using lower frequency sidescan sonars. The low frequencies penetrate bottom surface layers of thin sediment to identify plow hazards and search objects while higher frequency systems reflect off of the water-sediment acoustic interface to present imagery devoid of harder material actually present.

I. INTRODUCTION

In 2009, Williamson and Associates (W&A) contracted Applied Signal Technology (AST) to provide the SAS components for a deep towed Remotely Operated Tethered Vehicle (ROTV). The ROTV will be used to acquire improved sidescan resolution with co-located bathymetry to perform deep water survey and search operations. Through the early part of 2010 work has progressed with the production of the system, which is planned to commence sea tests during the early autumn of this year. The vehicle will be called the

PROSAS Surveyor PS60-6000, employing the trade name AST has applied to their 175kHz system.

II. PROSAS SURVEYOR PS60-6000 SYSTEM DESCRIPTION

A. Sensor Platform

The vehicle is a variant of the two part tow system which has been used successfully by Williamson and Associates on their AMS-120, AMS-60 and SeaMarc-30 systems for many years.

The vehicle comprises a 2000 lb depressor weight with a 50m neutrally buoyant tether to a neutrally buoyant sensor platform. The sensor platform provides a framework to hold the SAS transmit and receive arrays and electronics, Inertial Navigator System (INS), Doppler Velocity Log Sensor (DVL), Sound Velocity Profiler (SVP) and an acoustic beacon which is used for USBL tracking.

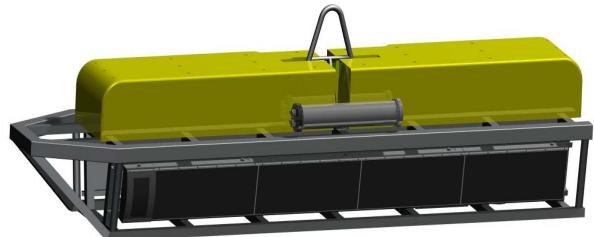


Figure 1. Model of PROSAS Surveyor PS60-6000 Sensor Platform

The sensor platform also includes an acoustic release mechanism which may be triggered from the surface, either via the tether telemetry or acoustically. In response to this trigger, drop weights are released, the tether to the tow umbilical is cut and the vehicle begins an ascent to the surface.

In the event of an emergency release USBL tracking would ideally be maintained during the ascent through the water column. The vehicle is equipped with a xenon strobe and a radio transmitter/direction finder for locating the vehicle once on the surface. The sensor platform is heavy and includes 2300lbs of syntactic foam to provide buoyancy countering the weight of the sensors and the framework.

B. Synthetic Aperture Ancillary Sensors

The sonar is designed to operate at ranges of up to 1500m per side. To achieve these ranges, the system must operate at an altitude of around 150 – 200m. There is the possibility that at times it might be desirable to operate the system at even higher altitudes, perhaps compromising image performance for the additional assurance of obstacle avoidance. The INS fitted to the platform requires a velocity over ground from a DVL sensor. None of the commercially available DVL systems were designed to operate at these altitudes and these depths, so the production of a new, 150kHz DVL was commissioned from RDI Teledyne to support this program. The new design is based on RDI's existing 150kHz systems, with some adjustments for improved reliability (survivability) at very high pressure

The DVL provides speed over ground aiding to the inertial navigation system. In this system we are using a Kefratt T18 sensor. Even using the 150kHz DVL system, with the vehicle operating at such depths, it may take up to 3 hours from the time that the system is denied GPS, to the point which the DVL achieves bottom lock. During this period, if the system is allowed to operate in a free inertial mode, any hope of achieving absolute geo-registration of data received from the sensor is lost. An IXSEA Posidonia SSBL system is used with an Oceano RT2500 SSBL transponder fitted to the vehicle to provide an absolute positioning reference of the vehicle.

C. Synthetic Aperture Sensor

The synthetic aperture sonar used in the system operates with a center frequency of 60kHz, with an operational bandwidth of 15kHz. The system is composed of a number of modular receivers, separate transmit transducers and a titanium pressure vessel which houses control and telemetry electronics, power amplifiers and the inertial navigator.

The receive arrays are fabricated in modular sections, each 1.08m in length. The receiver is an off-resonance 1-3 piezocomposite transducer, with a resonant frequency of around 120kHz. The composite transducer is backed with syntactic foam and is shielded with a syntactic acoustic damping material designed to provide good front to back isolation. Each module contains eight staves. The eight receiver staves are spaced on a 13.5cm pitch, providing a theoretical along track resolution of 6.75cm from the SAS. Each element is divided vertically into two sections, each individually addressable, allowing the vertical beamwidth of the receiver to be set to 35 degrees, 16 degrees or 10 degrees, depending on the selected section(s). Each receive stave comprises three elements, resulting in a three line Vernier interferometer to provide bathymetry information. Bathymetry is used both to provide a topographical picture to the operator

and to provide the terrain model to the SAS motion compensation algorithm. Receive signals from the array are fed into the rear of the housing where they are digitized and sent to the surface for processing.

D. Data Processing & System Performance

The processing system produces simultaneous SAS imagery, multibeam sidescan imagery and interferometric swath bathymetry.

As with its high frequency equivalents, the PS60-6000 relies on a multiple stage micronavigation and motion compensation process to adjust the data received from the arrays to provide an equivalent straight trajectory data set which can be fed into a frequency domain beamformer.

The process of navigating the vehicle begins with the velocity data from the inertial navigator. A full 3 dimensional model of the positions of the transmit and receive arrays is built up by integrating three dimensions of velocity data with the three dimensions of attitude data. The INS model is taken as the basis from which micro-navigation can proceed.

The sonar system is configured to ping at a rate which is determined by the advance rate of the sonar. This process allows the data from one phase center at the leading end of the sensor (a notional point which occurs mid-way between the receiver and transmitter position) to be placed coincident in along track space with the trailing phase center of the subsequent ping.

The two returns are cross correlated at a number of ranges, across the swath and the cross correlation phase shift may be used to provide a "micronavigation" correction to the solution provided by the INS.

A decision is made, based on the quality of the cross correlation and the proximity of the cross correlated results to the position from the INS, as to whether to update the position based on the acoustic results or to simply continue to navigate based on the INS solution.

The requirement for overlapping phase centers provides a limit on the forward advance rate of the sonar, as a function of both range and the number of receive modules fitted. With four modules, a speed of 2 knots can be maintained with a range setting of 1500m per side. The system is capable of being upgraded to a two transmitter per side configuration. Implementation of this upgrade will double the advance speed to 4 knots for a 1500m operation. This upgrade will probably be fitted into the system during 2011.

In the processing system, blocks of data, equivalent to three times the beamwidth of the receiver at the selected range (three times the length of the path travelled over which the return for a seabed reflector makes a significant contribution to the return signal) are collected and are re-sampled onto a straight line trajectory for processing. The length of the processing block is somewhat arbitrary; the longer the block the more efficient the processing, but more adjustments need to be made to form a straight line path, with a longer latency before the final image is produced. With a range scale of 1500m per side, the processing frame is 741m in length, with acoustic phase centers spaced every 6.75cm.

III. CONFORMATION TO IHO STANDARDS

Having carefully chosen the sensors to be used within the system, it is possible to determine the Total Horizontal Uncertainty (THU) associated with data received from the towfish. The THU is important because it provides a guide as to how accurately data received from the SAS system can be expected to be geo-registered within a mosaic.

Looking at standards for THU the primary point of reference is the International Hydrographic Organization (IHO) Special Publication No. 44 [1] of 2008. This defines four orders of survey as shown in Table 1 below:

Order	Special	1a	1b	2
Depth	< 40m	< 100m	< 100m	> 100m
Allowable THU to 95%	2m	5m + 5% d	5m + 5% d	20m + 10% d

Table 1. IHO Special Publication No. 44 Standards

For the PS-60, the vast majority of search and survey work will fall within Order 2 requirements (depth greater than 100m). Example depth data points with the following parameters were presented in a document produced at AST [2]:

- 100m depth, 50m altitude, 500m range
- 1,000m depth, 150m altitude, 1500m range
- 6,000m depth, 300m altitude, 1500m range

An analysis of the THU of the navigation solution has to take into account the different sources of horizontal uncertainty within the system including but not limited to:

- a. Uncertainty in the DGPS position of the towing vessel;
- b. Uncertainty in positioning of the towfish relative to the towing vessel;
- c. Uncertainty in INU and DVL in tracking the position of the towfish;
- d. Inaccuracy in measuring the speed of sound (SOS);
- e. Changes in towfish attitude (roll and yaw) impacting the horizontal positioning.

Based on research at AST the PS-60 will have THU values well within Order 2 standards. See Table 2 below. Notice that the THU at the 100m sample depth point is 2.98m. Extrapolation of the analysis of THU data shown in [2] to shallower depths shows the uncertainty continuing to fall until the water depth reaches around 50m, which is the altitude of the sonar. As all other uncertainties decrease with reduced depth the single strongest contributing factor to the THU in shoal waters is the altitude-range ratio. The PS60-6000 is expected to meet THU standards for Orders 1a and 1b and possibly Special Order surveys by reducing range as altitude drops.

Order	2	2	2
Depth	100m	1,000m	6,000m
Allowable THU to 95%	20m + 10% d = 30m	20m + 10% d = 120m	20m + 10% d = 620m
PS-60 THU	2.98m	10.94m	34.52m

Table 2. PS60-6000 THU vs. IHO Order 2 Standards

As with THU the Total Vertical Uncertainty (TVU) of the system is strongly dependent upon the roll uncertainty of the INS and also is a function of the accuracy of the bathymetry system. Bathymetry accuracy is estimated with data from tests carried out using the PROSAS Surveyor 175kHz sensor system, which has an identical vertical acoustic aperture (in wavelength terms) to the 60kHz sensor. Analysis of these data show that a $2\sigma = 0.066m$ uncertainty has been achieved out to ranges of 8 x altitude. Results of TVU including the bathymetry uncertainty along with added depth dependent and non-depth dependent uncertainties can be seen in Table 3 below.

Order	2	2	2
Depth	100m	1,000m	6,000m
Allowable TVU to 95%	a = 1.0m b x d = 2.30m	a = 1.0m b x d = 23.0m	a = 1.0m b x d = 138m
PS-60 TVU	a = 0.93m b x d = 0.05m	a = 1.45m b x d = 0.85m	a = 1.45m b x d = 5.70m

Table 3. PS60-6000 TVU vs. IHO Order 2 Standards

Note that TVU values for non-depth dependent values ("a" values) in a swath bathymetric system are strongly dependent on range. Whereas the worst case values of TVU exceed IHO standards these values can be decreased by reducing range to the point of IHO standard compliance. Analysis of data acquired from in situ testing of the Vernier interferometric bathymetry component of the PS60-6000 will determine the parameters required by operators of the system to meet IHO standards in all Orders of Special Publication No. 44.

The system is capable of being upgraded to synthetic aperture interferometric bathymetry system which will provide bathymetry data points at the same resolution as imagery (10cm). Implementation of this upgrade will afford data processors the ability to "bin" the high density data to more useable resolutions as required by survey specifications. This binning of data is expected to decrease the standard deviation of data within the bathymetry set thereby decreasing TVU and thereby THU at a given range.

IV. AREA COVERAGE RATES AND SYSTEM COMPARISONS

The commercial implications of a high resolution sonar with high area coverage rates provide interesting comparisons with competing technologies.

The use of traditional side scanning sonars will become less valuable where high resolution is required. Of course traditional side scan will have a place in many instances where the cost-benefit analysis shows the use of a high resolution system to be prohibitive. For example, a wide area search for a large metal hull will often find sufficient the use of a lower frequency with higher area coverage rates such as the SeaMarc systems. However, in highly active geology detecting even the largest metal hulls can be problematic with the resolution afforded by conventional sidescan sonars at which point a higher resolution system will be preferable. The higher resolution SAS will be particularly valuable in searches for smaller objects where there are geologic anomalies of all sizes.

In the search and survey arena Autonomous Underwater Vehicles (AUV's) have become a viable tool for carrying out sonar projects. AUV use is efficient in that they track the bottom well in areas with large bathymetry gradients and have a minimal turn time in comparison to ROTV's. Disadvantages of using an AUV include the absence of real-time data collection, battery powered operation requiring downtime and limited range and, finally, expense of systems.

To compare the benefits of the deep towed SAS with an AUV mounted side scan sonar is a complicated procedure involving site depth, search and survey block dimensions, contract requirements for bathymetric and image resolution, etc. In general, a deep towed SAS with high area coverage rate will excel where the depth is shallow, the search or survey block is long or some combination of the two. This owes to the fact that the deeper the water the longer the turn times between lines for a deep towed system. This disadvantage is somewhat offset by the need to bring an AUV aboard ship at intervals to change or refresh power supplies and to download data.

An ideal application for the long range, high resolution PS60-6000 is in a pipeline or cable route survey. These long routes traditionally require running between three and five passes with conventional sidescan sonars to achieve 200% ensonification of the seafloor while providing bathymetry densities that will meet specification. With a completed PS60-6000 system, which includes a gap-filling sonar, the survey corridor may be 100% ensonified with one run down the center of the line to provide sub-bottom profiler data of the intended burial route. A second pass could then be made for a

different look at the seabed features, add to bathymetry data point density and to infill any shadowing that may have occurred on the primary pass. The resultant imagery will be higher resolution than current surveys yield but in a fraction of the time. This savings of vessel and equipment spread time could have dramatic consequences in terms of overall job cost to the client.

V. BENEFITS OF USING LOWER FREQUENCY, HIGH RESOLUTION SYSTEMS

It is a well known fact that lower frequency sonar will penetrate sediment more efficiently than a higher frequency equivalent. Low frequency sonar has been used effectively not only for the benefits of longer range capability but also for the ability to image geology and debris fields that may be covered by a veneer of sediment. The combination of high resolution with low frequency sonar is a benefit to customers who want the ability to resolve fine details of small, slightly buried objects. In a recent cable route survey a 60kHz sonar was used subsequently to a 200kHz sonar with interesting results. With the higher frequency system the bottom type appeared to consist of soft sediment, including mud and clay, and a few small reflectors scattered around the field. Analysis of co-located 60kHz data revealed that the small reflectors were actually the tops of harder debris that persisted throughout almost the entire local site. This revelation resulted in the customer's representative asking to use the 60kHz system for the remainder of the survey to minimize hazards during subsequent plowing operations.

VI. CONCLUSION

The use of Synthetic Aperture Sonar in deep ocean search and surveys is a natural extension of the technology. The first ProSAS Surveyor PS60-6000 system is currently in production and is due to be integrated and to begin sea testing during September and October of 2010. This system will be the first synthetic aperture sonar to enter the commercial deep surveying marketplace and will provide a significant improvement in the imagery, bathymetry and productivity that can be achieved with conventional deep surveying tools. It will be interesting to watch the marketplace over the next few years to see how the adoption of this type of high resolution technology transforms the expectations and operational requirements for deep ocean search and survey.

REFERENCES

- [1] International Hydrographic Organization, Special Publication No. 44, IHO Standards for Hydrographic Surveys, 5th Edition, February 2008
- [2] B. Barrett, "Bathymetry Accuracy of PS60 System", Applied Signal Technology, Inc. Internal Document, unpublished.