EXECUTIVE SUMMARY

Synthetic Aperture Sonar (SAS) processing techniques have been used to generate underwater acoustic images with range-independent resolution over wide swath widths. This achievement in underwater image acquisition though requires significant processor and memory capability to handle the complex SAS signal processing algorithms and enormous image data sets. Newly developed SAS processing software implemented on high-speed processor boards permits the successful implementation of SAS onboard autonomous underwater vehicles.

SYNTHETIC APERTURE SONAR CONCEPT

Historically, improvements in side-looking sonar system resolution have been achieved by increasing the lengths of the arrays and by using higher acoustic frequencies. Although narrower beams at higher frequencies resolve finer detail, physics and operational constraints put upper limits on side-look sonar system capabilities. High frequency acoustic signals do not propagate to useful ranges for large area high resolution search. Extremely long arrays are difficult to implement on low-cost easily-handled underwater vehicles.

Synthetic aperture sonar techniques overcome these two limitations by synthesizing an extremely long array with multiple successive images from a conventionally-sized array. The array length, also referred to as the physical aperture, is extended by coherently combining successive images during the array’s travel through the water creating a larger synthetic aperture. Resolution is increased dramatically. With the larger synthetic aperture, lower acoustic frequencies can also be used which increase the effective range of the sonar system.

The most significant advantage of employing synthetic aperture sonar techniques is the achievement of range-independent resolution. As opposed to a conventional 50kHz side-scan sonar system whose resolution decreases rapidly as the distance from the array increases, a 50kHz SAS system can deliver 4 inch resolution over an entire 2000 yard swath. A 120kHz system could deliver 1 inch resolution over an entire 600 yard swath.

SYNTHETIC APERTURE SONAR IMPLEMENTATION

In order to achieve the advantages of SAS in operational sonar systems optimized for underwater vehicles, several unique issues have to be addressed:
Figure 1. Full swath, full resolution, real-time onboard SAS processor data flow.
1. Vehicle motion measurements. Since the synthetic aperture is generated over a period of vehicle travel underwater, the motion of the vehicle during that time period has to be known accurately in order to reconstruct the image properly. Vehicle motion sensors and advanced motion compensation signal processing are required to generate a SAS image.

2. Image processing and data storage capability. Instead of classic side-scan sonar beamforming, SAS signal processing requires a more complex set of processing algorithms. A SAS image processing flow path which identifies these complexities is shown in Figure 1. During a SAS 50kHz 2000 yd swath survey with 4 inch resolution millions of pixels per minute are processed and stored. These processing and storage requirements necessitate advanced computer processor boards and memory devices.

3. Array length / vehicle speed constraint. In order to generate a SAS image, one “ping” must be acquired every half array length that the vehicle moves through the water. This requirement couples the maximum forward speed of the vehicle to the sonar’s array length. However, although the maximum forward speed of the vehicle during SAS data acquisition may be limited, effective area coverage rate is still maintained with the survey vehicle due to the increased swath width and a constant resolution maintained out to the end of the swath.

SYNTHETIC APERTURE SONAR PROCESSOR DESIGN FOR AUVs

The computational complexity and large data storage requirements associated with SAS image processing have prevented until recently the real-time generation of SAS images. Image formation has been accomplished most commonly by post-processing only portions of the acquired data set. Attempts to process SAS data with time-domain based algorithms in one formulation requires the parallel operation of several dozen processors. These limitations have restricted the effective implementation of SAS into operational undersea vehicles.

However, with the formulation of the SAS processing steps in frequency-domain algorithms, similar to synthetic aperture radar, Dynamics Technology, Inc. (DTI) has succeeded in developing a SAS Real-Time Processor (RTP) that operates on a single commercial processor board.

The DTI SAS Real Time Processor algorithms were designed specifically for application to AUVs with the following features:

A. Capability to accept sonar array inputs matched to AUV sizes and missions.

B. Capability to accept conventional AUV motion sensor data inputs.

C. Capability to accept conventional AUV navigation and time inputs.

D. Ability to perform motion estimation and compensation processing tasks for the complete range of expected AUV motion.
E. Ability to process in real-time full swath width SAS imagery.

F. Storage capability for full swath width, full resolution SAS image output.

G. Storage capability for raw data storage.

H. Interface capability with image display software using standard TCP/IP protocols.

I. Upgrade capability for automatic target recognition features.

Together with Boeing Ocean Systems under a strategic partnership, DTI is currently porting the SAS RTP software to a Synergy G4 processor board running VxWorks. This processor board along with three 2G memory cards comprise the computer hardware required for an AUV on-board SAS real-time processor.

A near-term application for the Boeing/DTI SAS RTP is the Osiris AUV shown in Figure 2. The Osiris AUV is being developed as a joint venture between Boeing, Oceaneering International, and Fugro for commercial survey and inspection operations.

SAS IMAGE DISPLAY AND ANALYSIS

Post AUV mission display and analysis of acquired survey data is a critical aspect of commercial vehicle operations. To meet the requirement for easily interpretable visual data, DTI's SAS RTP outputs the SAS data in conventional waterfall side-scan image format for the operator. In addition, the raw data, collected from the sonar array transducers prior to processing is saved to allow more advanced processing and interpretation if required by the operator.

The commercial standard TCP/IP communications protocol implemented by the DTI SAS RTP for data output allows the potential direct interface with a variety of commercial display and analysis software packages.

Under a joint development project with Triton Elcis, DTI interfaced the SAS RTP output with the Triton Elcis Isis Sonar Display and Analysis Workstation. The Triton Elcis display software supports the presentation of DTI RTP SAS data in all of its standard formats for a full capability presentation of acquired data. Together with other AUV system sensor data, SAS output can be displayed in the Isis Waterfall, Wiggle, Voltage Scan, Real-time Mosaic, Track Reconstruction, Bathymetric Map and Image and Target Analysis Tools modes. This capability, shown in Figure 3, is significant for all future government and commercial SAS system users.

Figure 2. OSIRIS AUV
CONCLUSION

Synthetic aperture sonar techniques provide the capability for range independent, high resolution underwater imaging for all AUV survey, inspection, and search operations. Ideal applications are not limited to oil and gas exploration, marine construction, telecommunications and pipeline route surveys, underwater installation inspections, and geological and environmental surveys.

Synthetic Aperture Sonar processing software newly developed by Dynamics Technology, Inc. and implemented on high-speed processor boards by the Boeing/DTI team permits the successful implementation of Synthetic Aperture Sonar onboard autonomous underwater vehicles. This capability in conjunction with the Triton Elics Isis display and analysis capability greatly enhances all underwater acoustic search and survey operations.

Figure 3. Triton Elics Isis display and analysis of synthetic aperture sonar data.