# Real-Time SAS Processing for High-Arctic AUV Surveys


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*Abstract***— Interferometric Synthetic Aperture Sonar (InSAS) delivers ultra-high range independent image resolution with 3D seabed bathymetry at higher Area Coverage Rates (ACRs) and resolution than can be achieved with traditional physical aperture limited sidescan sonar. The along track resolution is achieved by synthesising the required aperture length by moving a physical aperture while sampling the field of view. The result is a compact power efficient solution ideally suited for use on Autonomous Underwater Vehicles (AUV) and towed platforms.**

**This paper will discuss the advantages of SAS as a tool for search and survey applications, including a detailed analysis of the processing and data handling workflow. Example workflow steps include SAS processing (image and bathymetry formation), georeferencing, mosaicing, data formatting, map generation, data storage, data recovery and data visualization.**

**In August 2014, Kraken Sonar Systems participated in the Victoria Strait Expedition to search for the missing ships from Sir John Franklin's doomed Arctic expedition. The expedition team used a variety of sonar survey tools, including a Kraken InSAS system, installed onboard the Arctic Explorer AUV owned by Defense Research and Development Canada (DRDC). Results from the search will be presented, as well as a discussion of the application of AUVs for high-arctic seabed survey.**



*Index Terms***— Synthetic Aperture Sonar, Interferometric Synthetic Aperture Sonar, real-time sonar processing, arctic survey**


## I. Introduction

Interferometric Synthetic Aperture Sonar (InSAS) combines ultra-high image resolution with 3D seabed bathymetry and superior area coverage rates. InSAS offers high resolution imagery at longer ranges than conventional side-scan sonars, done by replacing traditional sonar hardware with sophisticated signal processing software. The principle of InSAS is that the receive transducer array is "synthesized" in software by the coherent recombination of many sonar pings overlapping an area of interest. This represents a major savings in sonar hardware and enables much higher resolution than is possible with conventional sonars.

InSAS systems use two vertically separated arrays to produce bathymetric maps that are exactly co-registered with the corresponding SAS images. This combination of synthetic aperture processing and interferometry solves the problems of limited resolution and coverage rates encountered with conventional swath bathymetric sonars and multibeam echo sounders, and allows for significantly increased survey efficiency. When the InSAS bathymetric resolution approaches that of the corresponding SAS image, it becomes possible to overlay the imagery and bathymetry to create a 3D images of the seabed. The ability to generate centimeter-scale resolution in all three dimensions has the potential to provide significant improvements in the detection, classification and identification of small seabed objects. Additionally, the high resolution, large swath coverage and high accuracy bathymetry can significant increase operational efficiency for seabed survey and hydrographic applications.

The traditionally high cost, complexity and export considerations of InSAS technology have restricted access to only a few military and defense applications, and prevented widespread use of the technology in the commercial survey market. However, commercial InSAS systems have recently become widely available, and have approached the technology level of being considered "off-the-shelf", competing directly with high-end sidescan sonars and multibeam echosounders. As a result of the high resolution, and the commercial availability, offshore survey operators are now requesting SAS as a survey tool for their customers.

Kraken Sonar Systems is a marine technology company headquartered in St. John's, Newfoundland, and engaged in the development and production of high performance InSAS systems, such as the AquaPix® (Figure 1). Kraken has successfully delivered several InSAS systems integrated on a variety of AUVs and towed platforms to both commercial survey and defense customers.


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| | InSAS1 | InSAS2 | InSAS3 | InSAS4 |
|---|---|---|---|---|
| Operating Speed | 3 kts | 3 kts | 6 / 8 kts | 10 /15 kts |
| Range | 132.5m | 265m | 200 / 150m | 160/105m |
| Swath | 265m | 530m | 400/300m | 320/210m |
| Area Coverage Rate (Without Gap Filler) | 1 km²/h | 2.1 km²/h | 3.2 km²/h | 4.2 km²/h |

**Figure 1: AquaPix® InSAS Configurations**

The AquaPix InSAS delivers area coverage rates in excess of 2 $km^2$/hr, ultra-high 3x3cm seabed image resolution and co-registered bathymetry at up to 6x6cm resolution which exceeds capabilities of currently available multibeam and sidescan sonar systems.

The InSAS system is modular, and by the addition of physical modular receiver arrays, the InSAS system can operate at higher speeds, or correspondingly longer ranges. The InSAS system employs two sets of receive array elements, a long-range and a short-range row, within each vertically displaced receiver array. SAS processing is performed individually on each of these arrays, and subsequent interferometry performed on the corresponding displaced short range and displaced long range images. This allows the InSAS to achieve very good coverage in very shallow water (<10m) in both the near and far field, with a typical start range of 1.5x altitude, and an end range of 10x altitude, as shown in Figure 2 below

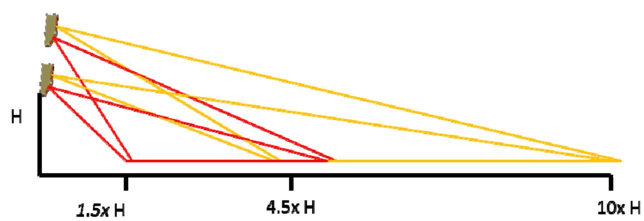


**Figure 2: InSAS Coverage Illustration**

One of the key challenges faced in transitioning SAS technology from the military and defense applications into the commercial survey market lies within the actual workflow. SAS data processing is computationally very intensive, requiring powerful computing hardware for post processing. Such hardware may be too large or power hungry to carry onboard an AUV, therefore raw SAS data must be recorded and recovered after a mission for post-processing. Raw SAS data is very high bandwidth, creating data storage, handling and processing challenges when employing traditional methodologies using onboard storage media. Once data is recovered, and processed, the resulting high-resolution imagery must be georeferenced, processed and compiled into bathymetry maps and imagery mosaics. Even after processing, this high resolution SAS data still requires significant bandwidth.

Several technologies and methodologies have been developed in order to meet these challenges, and further realize the significant benefits of InSAS technology for commercial survey applications.

## II. High-Arctic Search and Survey

Ultra high resolution imagery and high area coverage rates make InSAS systems the ideal tool for large area search and survey applications. Small debris and man-made objects can be easily identified in the sonar images, allowing single pass detection and classification of targets which would traditionally require a second pass with a higher resolution sidescan, or optical inspection with an ROV's video camera. Sample InSAS imagery of manmade objects on the seabed can be seen in Figure 3.

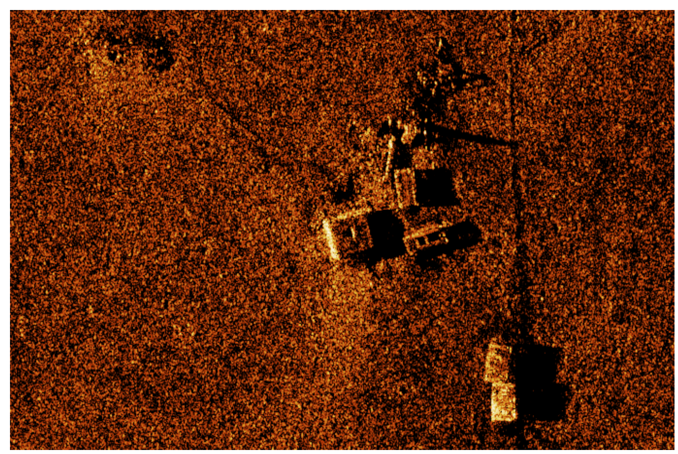

**Figure 3: Man-made objects easily identified in SAS images**

In August 2014, Kraken Sonar Systems was invited to participate in the 2014 Victoria Strait Expedition. Led by Parks Canada, the goal of the Victoria Strait Expedition was to locate the shipwrecks of HMS Erebus and HMS Terror, both part of Sir John Franklin's ill-fated 1846 expedition to locate the Northwest Passage. With a goal of surveying over 1,200 $km^2$, the 2014 Victoria Strait Expedition would exceed the cumulative search areas covered in the previous search efforts since 2008. Given the age of the wrecks and the high volume of ice in the Victoria Strait that could have damaged or destroyed the wrecks, the potential was very high that searchers would be looking for small debris on the seabed rather than fully formed wrecks.

DRDC's Arctic Explorer AUV is ideally suited for high arctic seabed survey applications, having been developed specifically for under-ice surveys in support of Canada's UNCLOS submission. With a maximum range of 450 km in a single mission, and equipped with Kraken's InSAS2 system, the Arctic Explorer AUV has the potential to achieve coverage rates unattainable with towed sidescan systems, at extremely high resolution. The predicted maximum range of the InSAS2 is over 250m per side, resulting in a swath of over 500m, with ultra-high resolution 3x3cm imagery even at maximum ranges. At a nominal survey speed of 3 kts, and including second passes to provide overlap and achieve 100% coverage of the nadir gap, it was expected that the designated search area could be completely surveyed in a number of weeks, an order of magnitude faster than could be achieved with traditional sidescan sonar systems. A photo of DRDC's Arctic Explorer AUV can be seen in Figure 4.

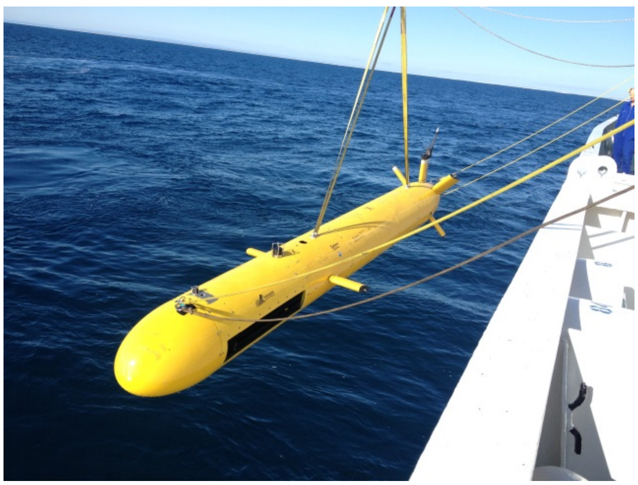

**Figure 4: DRDC's Arctic Explorer AUV**

Seabed search and survey in the Arctic presents several unique challenges compared to more southern search zones. Only a fraction of the Arctic seabed has been charted, which creates navigational challenges for operating survey vessels or support ships. As shown in Figure 6, large white regions represent uncharted areas in the Victoria Strait and could contain potentially hazardous seamounts or other hazards to navigation. Larger vessels must follow previously charted paths to avoid the potential risk of damage or running aground. However, AUVs such as the Arctic Explorer are ideally suited for operating in these unknown areas, as the AUV's control system includes bottom avoidance algorithms and forward looking sonars to assist in navigating in unknown terrain.

An additional benefit to operating an AUV system equipped with interferometric SAS systems is the simultaneous production of co-located bathymetry as well as high resolution SAS imagery. InSAS bathymetry can be georeferenced with AUV navigation data and depth sensor measurements to produce absolute bathymetry of the survey area. This data can then be post-processed with hydrographic charting software into contour maps of the survey area, and used as updated navigation charts for future vessels operating or transiting in the search area. Sample data can be seen in Figure 5 below.

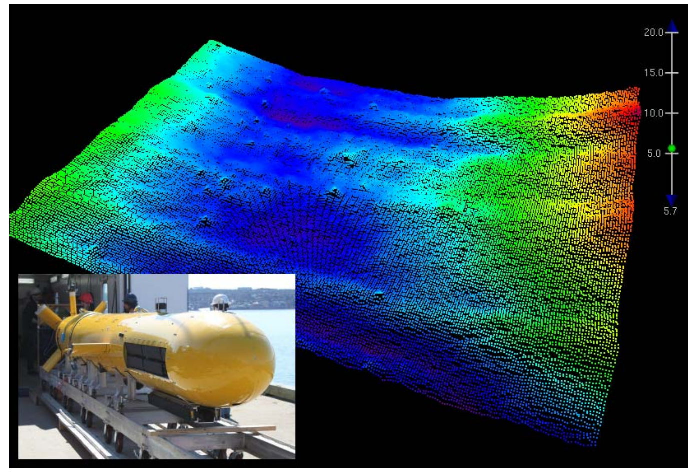


**Figure 5: Sample Co-located InSAS Bathymetry**

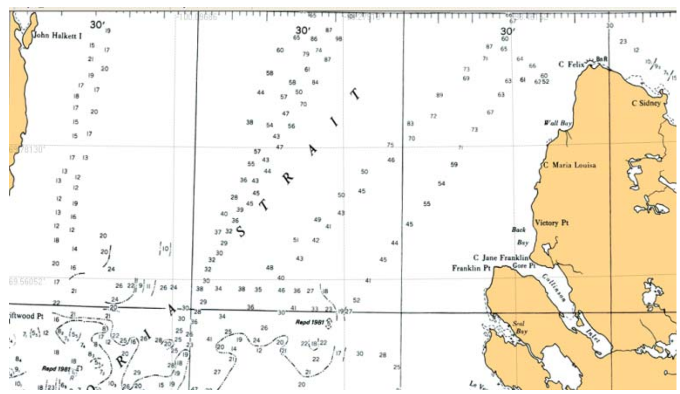


**Figure 6: Victoria Strait Search Area**

Despite the challenges of operating in the Arctic, there are some benefits unique to the Arctic environment. Sonar performance is highly dependent on water temperature, which directly impacts the speed of sound in water and the propagation loss of the sonar signal. Sub-zero water temperatures in the Arctic Ocean have the potential for excellent sonar performance unachievable in other areas. This performance improvement was demonstrated by increasing the maximum range of the InSAS2 system beyond the theoretical limitation of 265m, and up to a maximum range per side of 280m, as shown in Figure 7 below. This increased range allowed for an increased area coverage rate in excess of 2.2 $km^2$/hr, while still maintaining 3x3cm resolution even at these long ranges.

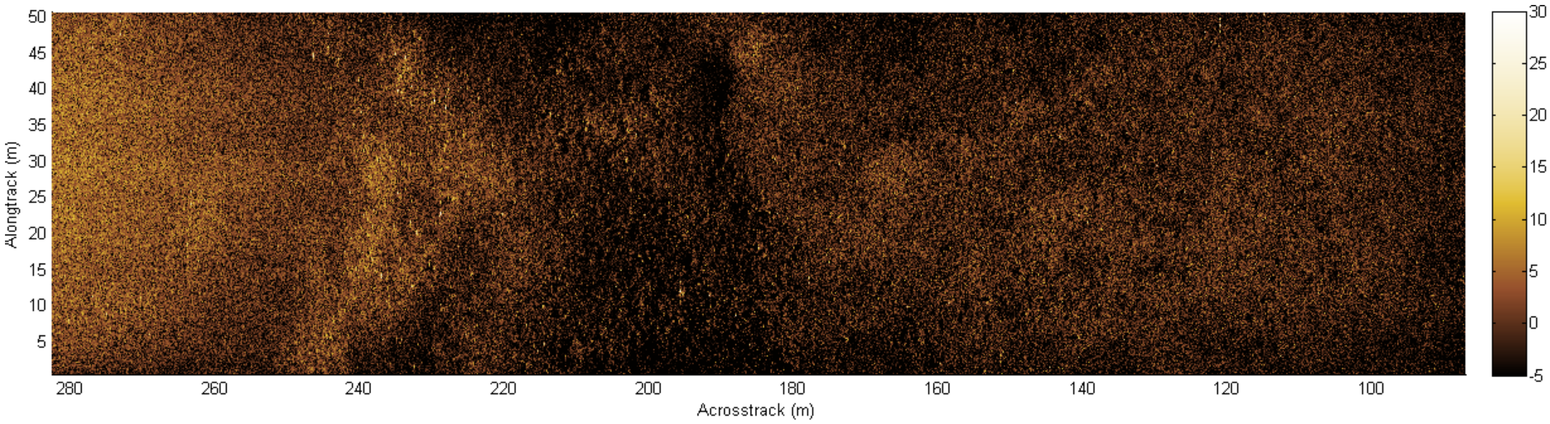


**Figure 7: InSAS2 max range exceeds 280m per side in subzero Arctic water**

## III. SAS PROCESSING CHALLENGES

Operating SAS systems onboard AUVs introduces several unique challenges not present in traditional sidescan sonar systems. Figure 7 below illustrates the typical AUV SAS processing workflow.

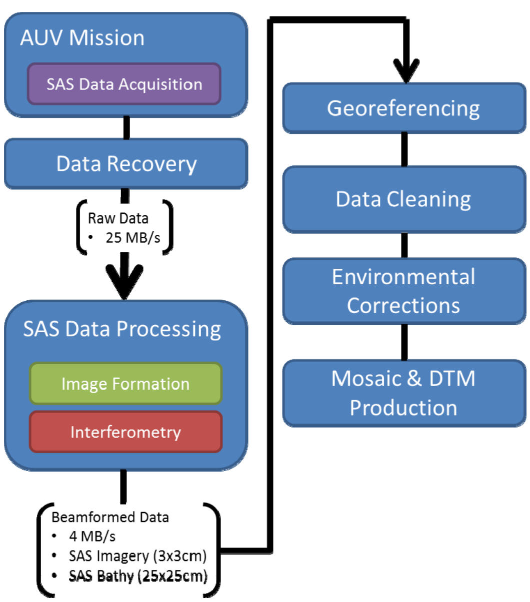


**Figure 8: Typical SAS Data Processing Stages**

SAS processing has a significantly higher computational requirement than traditional sonar systems, due to very high bandwidth and large number of sampling channels. A typical Kraken InSAS1 system is composed of four 32-channel receivers, yielding a total of 128 receiver channels. After basebanding, each receiver channel samples data at 50kHz, and each sample is a 32 bit complex number. Therefore the resulting raw element-level data amounts to approximately 25MB/s. Larger InSAS systems require more bandwidth; InSAS2 requires twice the number of receivers as InSAS1 (4 per side vs. 2 per side), for a total of 256 receiver channels, with a total bandwidth of 50MB/s. This high bandwidth data output is supported with a standard 1000BASE-T Gigabit Ethernet link, and is then recorded onboard the sonar's internal storage.

Due to the challenging computational requirements and high bandwidth data handling, many AUV SAS systems require that SAS data be post-processed to achieve full SAS resolution, with onboard realtime processing only offering a reduced resolution comparable to that of a sidescan. The resulting workflow requires a number of stages from data acquisition to chart production, as shown in Figure 3. Recorded data must be downloaded from the AUV before processing can proceed, and processing speed will depend directly on the hardware and SAS algorithms available to the sonar operator.

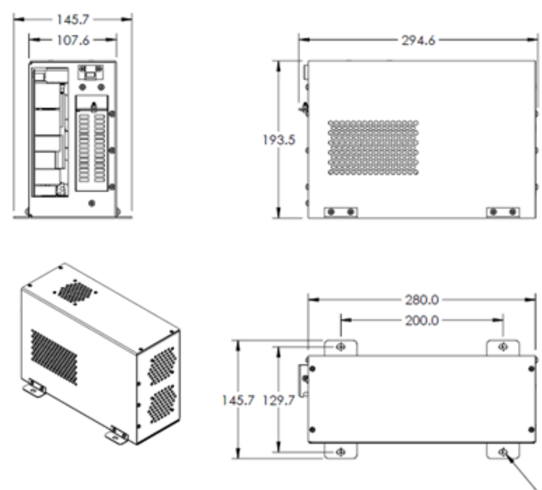


**Figure 9: RTSAS Processor Dimensions**

Kraken's highly efficient SAS processing algorithms are able to use off the shelf processing hardware to meet these processing requirements. Leveraging GPU acceleration to significantly increase processing speed, and reduce overall processing, Kraken's INSIGHT software has enabled faster than real-time processing on standard gaming laptop hardware consisting of a mobile CPU and GPU. These results are achieved on a standard processing laptop, using i7 2.4GHz Quad-core CPU, 8GB RAM, and an NVidia GeForce GTX660M GPU. With this hardware, SAS data can be processed in 3-4 times realtime; for example, 1 hour of SAS data can be processed in 15 minutes. While this result is technically impressive, and significantly reduces the overall workflow, it still requires a potentially unnecessary stage of post-processing. Given that the hardware requirement for faster than real-time processing can be easily met with off-the-shelf mobile laptop hardware, it is therefore reasonable to expect that real-time onboard processing on an AUV could be achieved with similar or even lower-power hardware.

In response to this requirement, Kraken has proposed a Real-Time SAS Processor, the RTSAS. Based on commercially available mobile computing hardware, the RTSAS is a rugged, small-form factor subsystem for the real-time processing of AquaPix InSAS data. Designed not just for maximum imaging performance but optimal performance per watt, the RTSAS Processor creates a powerful, compact SAS processing capability.


**Figure 10: RTSAS Processor with mug for scale**

The RTSAS processor allows several stages of the SAS processing workflow to be compressed into one onboard, online processing stage. The RTSAS processor takes in real-time raw SAS data, and performs SAS micronavigation, image formation and interferometry in full resolution in real-time. The inclusion of the AUV navigation data stream (latitude, longitude, depth and heading) allows for real-time onboard georeferencing to take place as well, further reducing the overall workflow. The resulting dataset available when the AUV mission completes consists of full-resolution imagery and bathymetry, ready for mosaicking and production of digital terrain models (DTMs).

In addition to the reduced processing time in the overall SAS data workflow, the resulting processed imagery and bathymetry is an order of magnitude smaller than the raw data. At approximately 4MB/s, the processed SAS data could be recovered from the AUV in significantly shorter time, and could be reviewed wirelessly using off the shelf Wireless Ethernet hardware. This allows the operator to review processed SAS data without the necessity of recovering the AUV.

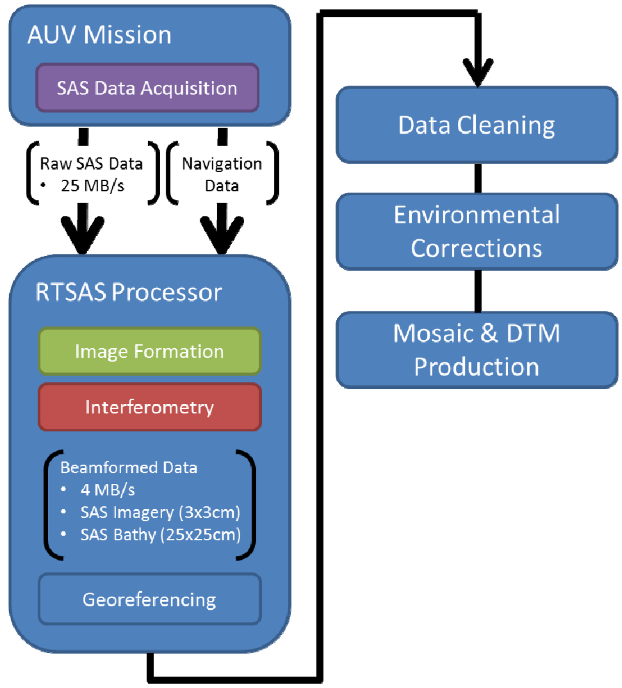


**Figure 11: SAS Data Workflow with RTSAS Processor**

## IV. Current and Future Work

Following the successful Victoria Strait Expedition and RTSAS trials, Kraken has continued to further develop the real-time SAS software, which needs to perform online troubleshooting and dynamic closed-loop tuning of SAS parameters for optimal survey efficiency, as a result of environmental or operational changes throughout the survey. In the case of towed systems, the RTSAS software is also continuing to develop to provide online monitoring and real-time visualization of both raw SAS data and beamformed SAS imagery and bathymetry, for online quality assurance and quality control.

Kraken is also engaging in a project with the software company CARIS, to develop a capability to further compress the SAS processing workflow, by automated the traditional post-mission tasks such as mosaicking, DTM production, environmental correction (tidal, sound velocity, etc.) and generated fully mapped solutions directly onboard the AUV. Kraken are CARIS are working together to allow InSAS data to flow into CARIS Bathy DataBASE technology, reducing the time taken to generate modern survey deliverables.

## V. Acknowledgements

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