TECHNICAL FEATURE

Multi-angle: the sonar the better!

Multi-angle-of-arrival estimates takes interferometric sonars to the next level — Innovation at Simon Fraser University, Canada

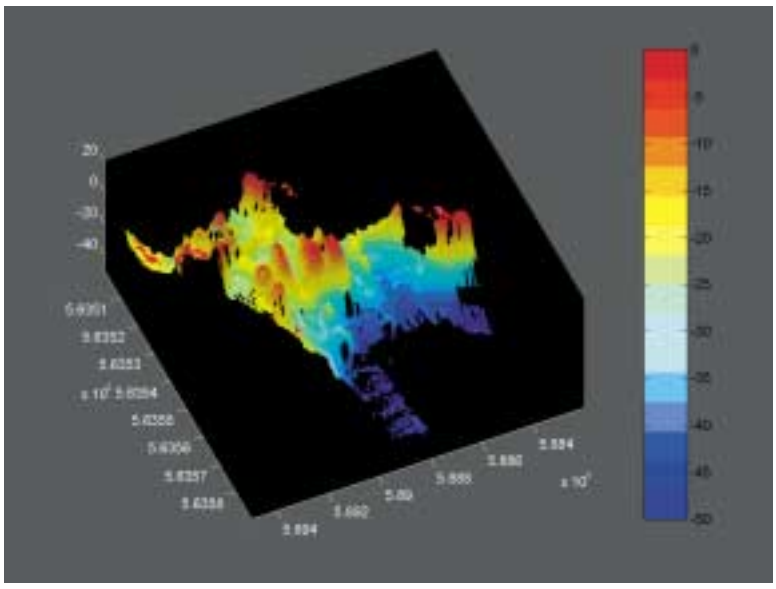
The Underwater Research Laboratory at Simon Fraser University, Burnaby, Canada has been carrying out work to investigate a new sonar imaging concept. This work has resulted in a breakthrough in multipath-angle-of-arrival estimates that can be applied to the principles of interferometry.

This technology has been developed into a 'prototype sonar' to provide high resolution 3D underwater acoustic mapping and imaging that exceeds the capabilities of interferometry but does not require a large beamformed array.

This technology has subsequently received a lot of interest from a number of sources ranging from the military, in the form of the US Navy's Office of Naval Research International Field Office (ONRIFO), to the oil industry, who recognise the potential for this in underwater surveys.

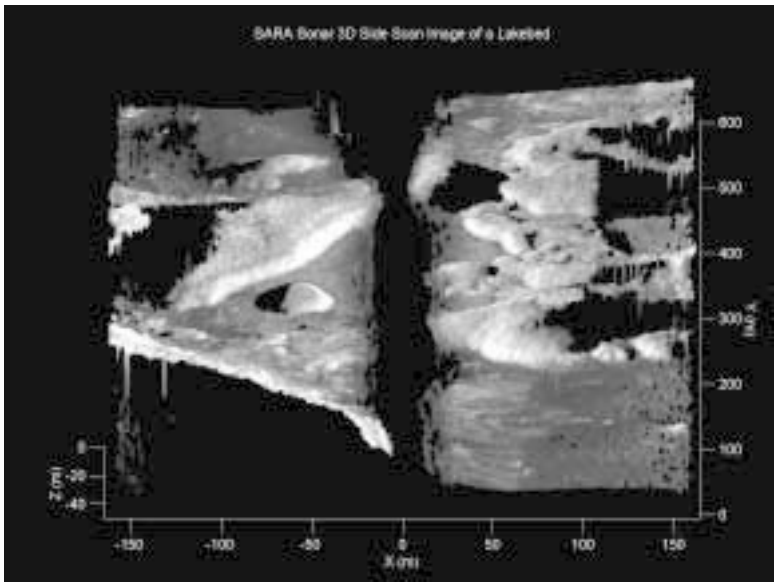
The Underwater Research Laboratory (URL), located within the Simon Fraser University (SFU), was established in 1989 with a mandate to teach the attitudes, approaches, methods, and skills associated with effective and responsible subsea science and engineering.

The laboratory is an academic laboratory, equipped with 100m^2 of floor space, a test tank, a four-channel coherent laboratory sonar (variable frequency from 10 to 600kHz), a six channel coherent field sonar (300kHz), a commercial side-scan sonar (330kHz), an automated beam pattern measurement system and facilities for making acoustic transducers (vacuum chamber, fume hood, oven). The laboratory also has its own autonomous underwater vehicle, *PURL III*.

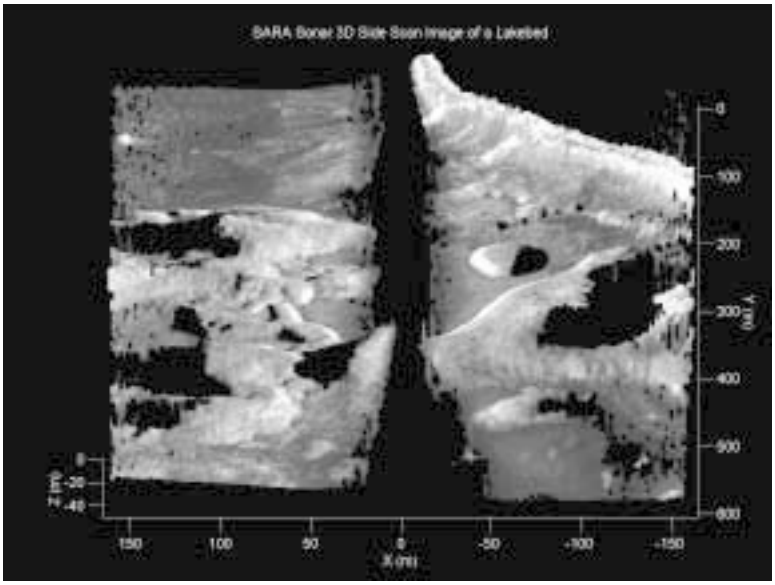


Three-dimensional image from the SARA Sonar (see next page)

The URL conducts research in underwater acoustics, sonar, bottom imaging, autonomous underwater vehicles (AUVs), bottom and water column surveys with AUVs, signal processing and target detection, with funding from research grants that are associated with projects. Sponsor organisations to date, include the Natural Sciences and Engineering Research Council of Canada, the BC Advanced Systems Institute and International Submarine Engineering.



Above: Three dimensional sidescan image produced by Sara sonar collected from the Pavilion Lake and Below: viewed by the opposite end and tilted by 10 deg



Swath bathymetry

Swath bathymetric sidescan offers both bathymetric mapping and sidescan imaging capabilities. The underlying principle of conventional Swath bathymetric sidescan is interferometry, wherein differential phase across the array elements is used to directly estimate the angle-of-arrival of an impinging plane wave as a function of range (time since transmit).

Its high resolution, simplicity and small array requirements, in comparison to beamformed systems, makes Swath bathymetric sidescan an attractive alternative for three-dimensional seafloor mapping and imaging. However, because Swath bathymetric sidescan is based on interferometry, successful application is limited to acoustic environments in which the acoustic backscatter can be accurately characterised by single angle-of-arrival estimate at each measurement time. If a multipath signal is returned, then this technique is limited, due to the inability to accurately characterise the angle-of-arrival.

Over the last five years, two principal workers at the laboratory, Professor John Bird and his research associate Dr Paul Kraeutner, have been researching and developing a new sonar imaging concept called Computed Angle-of-Arrival Transient Imaging or CAATI. The concept is based on the idea that increasing the number of concurrently resolvable angles-of-arrival will increase the complexity of the geometries that may be successfully imaged and mapped.

CAATI is a model-based method for estimating the backscatter arrival spectrum. The underlying principles are derived from the broad fields of high-resolution spectral estimation and angle-of-arrival estimation. In a number of 2D sonar-imaging applications (eg, sidescan, sector-scan) CAATI provides a method to add the third dimension (vertical relief) using only a small number of vertical array elements. Instead of beamforming in the vertical plane, CAATI uses angle-of-arrival estimation in a fashion similar to interferometry.

Like interferometry, CAATI assumes a time-varying impulsive spectral model. However, while interferometric systems (eg, Swath bathymetric sidescan) are rendered ineffective by concurrent arrivals from multiple angles (eg, multipath), CAATI is able to resolve as many as N-1 arrivals with an N element array (eg, with three elements a direct path and multipath can be separated).

Another technology being examined at Simon Fraser is the six-element 300kHz Small Aperture Range versus Angle (SARA) sonar. Recently, a US patent application has been filed and the project has reached the point of having an operational prototype. SARA affords both sidescan and sector-scan operations.

SARA incorporates a transducer array assembled from multiple sidescan elements stacked vertically at a spacing of approximately one half wavelength. Fundamentally, the prototype is a six-channel coherent sidescan/sector-scan sonar designed with wide receiver bandwidth and high sample rate/dynamic range capabilities for array signal processing research. SARA sonar together with CAATI signal processing provides high resolution 3D underwater acoustic mapping and imaging that exceeds the capabilities of interferometry

but that does not require a large beamformed array. Acoustic backscatter data collected using SARA and processed by CAATI offers substantial advantages over both beamformed systems (limited vertical resolution, expensive, complex) and interferometric systems (limited to simple imaging geometries).

The sonar (SARA) was mounted over the side of the boat (transducer depth of 1m) and linked via the Ethernet, to a surface computer for control and data logging. Additional survey routes using the SARA Sonar can generate a 3D rendition of the bottom floor terrain for feature base navigation for divers or underwater vehicles.

The concept of CAATI and SARA can also be used to form an accurate look-ahead sonar by reconfiguring the array along the horizontal axis, with a variable tilt angle that can be adjusted to address various platforms, and water depths.

Future work

The technique and the prototype sonar work well enough in their present form to be practical now. The physical configuration and signal processing techniques have been patented by SFU. The Underwater Research laboratory is building the next generation of SARA sonar, and other applications are being investigated such as Sector Scan (mechanical and electrical), look-ahead, and mine hunting.

Future research will include quantitative mapping experiments and an investigation of the ultimate limitations of the method. Future collaborative research can aim at enhancing the signal processing for speed and accuracy, acoustic array design issues, and electronics designed for signal integrity. Furthermore, the CAATI algorithm may be applied to any linear array and therefore can be used to enhance some multibeam sonars.

Recently, the US company Benthos has exclusively licensed the SARA/CAATI swath bathymetry sonar technology from SFU, and is partnered with the URL for future research (FY02-05) in developing an enhanced prototype system and eventually commercialising this technology.

With further research, the SARA/CAATI sonar can be made even smaller, and cost of production can be reduced. This sonar is suitable for mounting on both large and small towfish, AUVs and boats for bottom mapping and look-ahead applications. The URL's innovative efforts with SARA/CAATI can provide important data in support of studies into a number of coastal and environmental issues.

SARA Operating Specifications

Operating frequency:	10kHz-500kHz
Bandwidth:	Inductors and capacitors can be changed as required for a desired filter type, center frequency, bandwidth
Number of channels:	8 per stack
Transmit voltage:	400Vpeak
Sampling method:	evenly spaced, or quarter cycle pairs
Sampling rate:	up to 2MHz
Sampling resolution:	4bits (78dB instantaneous dynamic range)
Samples per ping:	up to 32K per channel
TVG control:	up to 2K digital TVG values per channel
TVG range:	120dB
TVG resolution:	9bits
TVG update rate:	up to 500kHz, synchronous with sampling
Host:	PC104 486
Remote data link:	Ethernet