MATERIAL IDENTIFICATION REFLECTIVITY KERNEL

6th Annual Entrepreneur's Forum
and Technology Showcase

A Rising Tide – Organizing for Success

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Center for Marine Robotics
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MIRK is a mature signal processing method for novel feature extraction for automatic target detection and classification using active sonar.

MIRK was adapted from airborne synthetic aperture radar technology to provide a discriminator for man-made objects under water.

Usage to date has been defense oriented: counter-mine and anti-submarine; but the product is adaptable to commercial applications.

Capability has been demonstrated using a variety of US Navy systems as well as a commercial-off-the-shelf prototype at ranges from 10m to 30km.

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Material Signatures

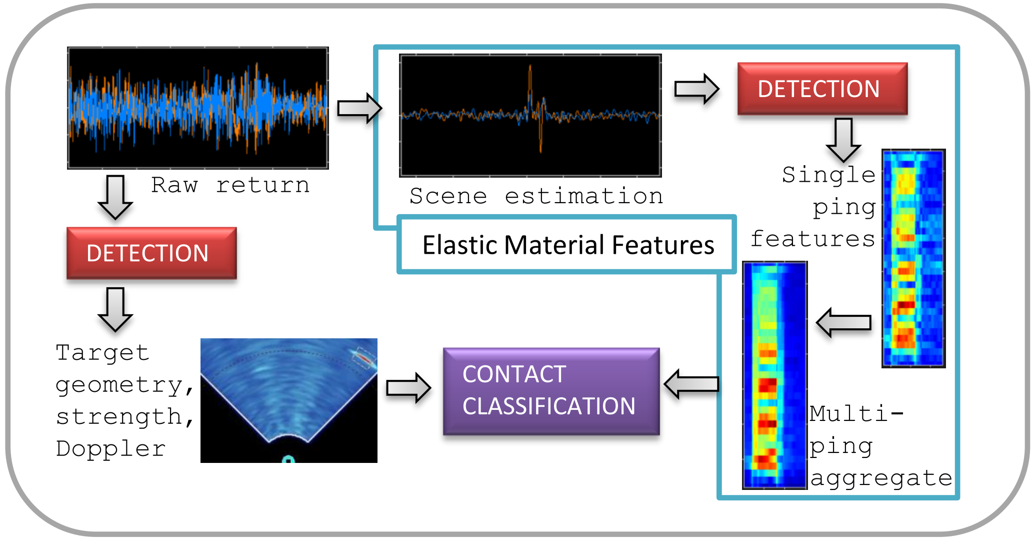
Measuring elasticity of an acoustic reflector provides insight into material composition.

MIRK uses a physics-based framework that models an echo as a convolution between an acoustic reflector and the transmitted signal. By substituting the typical match filter, which implicitly models an echo as a time-delayed, Doppler shifted replica of the transmit signal, with deconvolution, MIRK more accurately captures phase-information and short-time energy excitation of the target.

The underlying signal processing technique was originally developed for the detection of explosive pre-cursors from aerial surveillance platforms in support of counter-IED efforts in Afghanistan.

The application to sonar began in 2013 with the analysis of data collected at the NUWC acoustic tank using targets with identical geometry and different materials to test discrimination capability using acoustic excitation.

This led to projects to develop algorithms for torpedo sonars with the NUWC Weapons Analysis Facility, mine-hunting sonars in conjunction with the Raytheon Company, algorithms for the AN/SQQ-32 Navy sonar, AN/BQQ-10 submarine sonar, and other DoD-interest sonars, as well as material fault detection using hand-held ultrasonics.



MIRK supports, but does not necessarily replace, existing system signal processing. Fast enough for detection, robust enough for classification.

The novel feature provided by MIRK can help characterize sonar contacts using material characteristics in addition to existing discriminants. MIRK features can be used in concert with characteristics such as geometry, target strength, or Doppler to improve detection and classification performance.

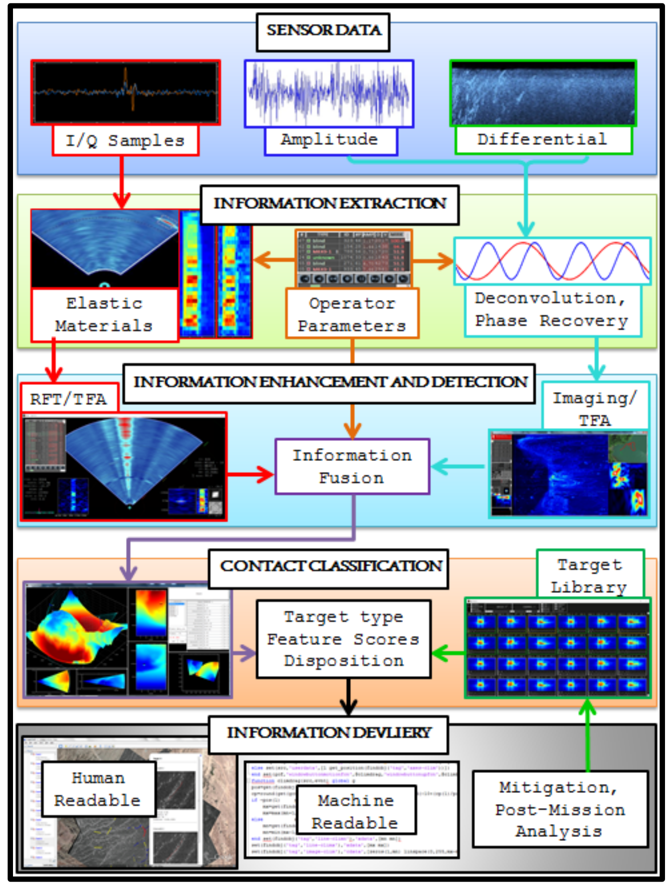
Sensor Requirements

MIRK is sensitive to bandwidth and frequency—material responses vary at different frequencies, and sufficient energy on target is required for the development of a robust signature.

While MIRK has proven capable using sub-kilohertz bandwidth at lower frequencies for long range target detection, discrimination is limited to large (i.e. submarine size) targets. In particular, cases where passive sensing, or Doppler-based active discrimination are infeasible, like the case of a bottomed-submarine, MIRK has excelled. At the other end of the spectrum, MIRK algorithms have been tested at ultrasonic frequencies for use with hand-held sensors to detect material de-bonding of submarine hull treatments.

Some of the data sets that MIRK has been applied to have contained shipwrecks, which are easily discriminable, based on their MIRK signatures, from other bottom clutter.

MIRK has also been adapted to function with harbor defense active sonars for discriminating between divers and marine mammals, although in that case, the most robust target signature was provided by the dive tanks.



Prometheus can provide a complete signal processing suite, or a single modular component for integration to an existing package.

- MIRK operates on complex beam-formed data, prior to match-filtering.
- Single-ping discrimination is possible, provided there is enough energy on target.
- Multiple pings allow the development of an aggregate feature that can mitigate noise.
- MIRK is affected by geometry, depending on the frequency of the interrogating signal: aspect diversity may provide better target characterization.

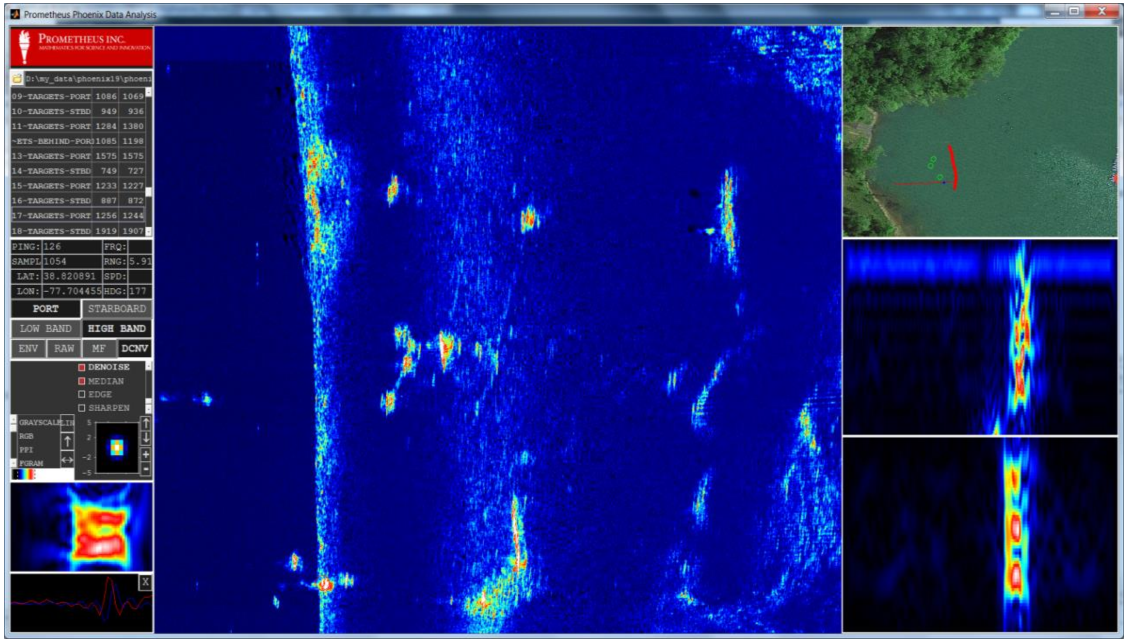
Information Extraction

MIRK provides a one-dimensional scene reconstruction and a two-dimensional time-frequency target response feature.

Depending on the discrimination problem, the feature-space provided by MIRK can be tuned to express gross material features, like the difference between an undersea ridge, and a lurking submarine, or fine-features like hull-coating de-bonding using hand-held ultrasonic for pin-point repair and maintenance.

For classification applications, the existence of robust ground-truth is paramount. Different sensors capture target material characteristics differently, so fine-feature discrimination requires training the MIRK feature-space.

For anomaly detection applications, MIRK may provide queueing for additional sensors, even without *a priori* information about likely sonar contacts.



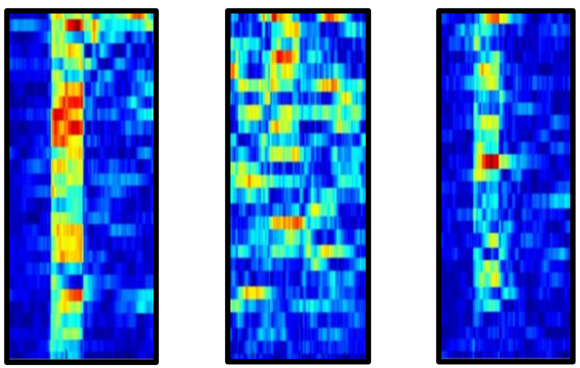
MIRK software package for a prototype, kayak-mounted, dual-band side-looking sonar. Time-frequency response feature space on right, below the aerial photo.

- Standard side-scan or synthetic aperture imaging can be coupled with MIRK features to provide a MIRK-layer to a GIS map of a scene. Specific regions of interest can be queried by an operator or analyst.
- MIRK operates in real-time and can indicate when a second pass may be advantageous if a low-strength target nonetheless exhibits features characteristic of a potential target.
- Post-mission, MIRK features can be incorporated into machine-learning target libraries to support automatic target recognition.

MIRK Successes
(and failures)

MIRK has been applied to a variety of sonars and problems. These examples show MIRK features at a variety of bandwidths and center frequencies.

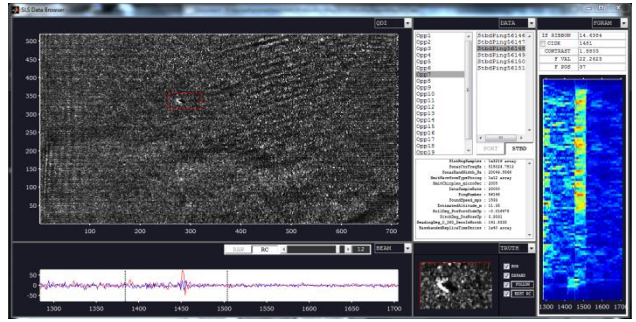
Not shown are submarine sonars or harbor security sonars.



Typical MIRK time-frequency feature space images.

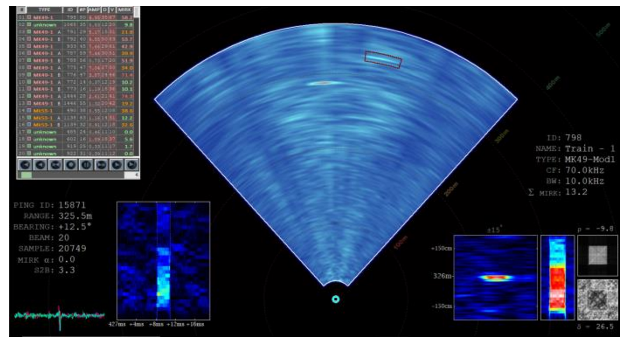
Frequency response varies over “short-time” and encapsulates the decay of acoustic excitation. These images correspond to peaks in a match-filter time series.

Left is an irregular steel canister, middle is bottom clutter (rock) that was strong enough to trigger an alert of a detection algorithm, right is a piece of metallic debris—a false-target for this exercise.



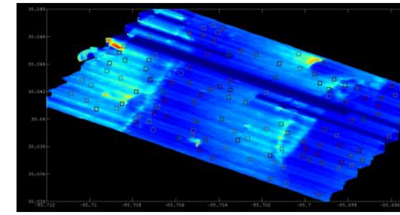
Side-look imager,

MIRK provided feature space



Forward-look volume mine-hunter,

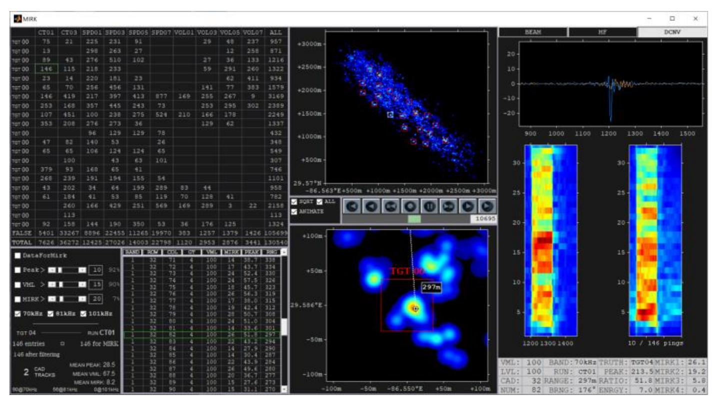
MIRK provided imaging and class scores



Side-look UUV,

MIRK provided GIS-layer

Target examples from a MIRK discrimination test



Helicopter towed array,

MIRK provided single ping feature score, multi-ping aggregate class scores, and aggregate feature space