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Material Identification Reflectivity Kernel (MIRK) for A New Approach to Mine and Submarine Target Discrimination

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Navy Applications

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1. **MINE DETECTION, CLASSIFICATION AND IDENTIFICATION**
   - Process is too slow; false targets too common
     - Detect & classify, post mission analyses, return to ID and neutralize
   - Seamless detect to engage desired; requires reduction in false targets
- **BASELINE TECHNOLOGIES**
   - Sonars with real time operator calls and/or computer aided **detection** and computer aided **classification**, CAD/CAC , visual/optical **identification** and **neutralization**

2. **NO DOPPLER/LOW DOPPLER SUBMARINE DETECTION/CLASSIFICATION**
   - ASW forces: submarines, surface ships, P3/P8 AC, torpedoes
- **BASELINE TECHNOLOGIES**
   - ASW sonars, sonobuoys & torpedoes: Doppler and target motion analyses are key parameters

3. **LONG RANGE UUV DETECTION AND TRACKING**
   - Submarines, surface ships, UUVs, port protection
- **BASELINE TECHNOLOGIES**
   - Adaptations of existing sensors

Technology Needs

- NEW SYSTEMS' CAPABILITIES
  - Single pass target/non-target indication
    - High target/non-target confidence
    - Major reduction in false targets
    - Doppler independent
    - Real time results
  - AFFORDABLE
    - Use existing sonar systems hardware
    - Parallel processing - current system processing unchanged if desired

Demonstrated Solution*: MIRK

- Echo returns from active interrogation of an underwater object contain *reflectivity kernel* (RK) clues
- Deconvolution - not a new problem/knowing transmitted signal and echo return, solve for RK
  - Unique mathematical technique devised by Prometheus to exploit existing information
  - Uses time vs. frequency domain approach
  - Highly stable, real-time processing
- Approach: Classify active sonar contacts based on material discrimination technique
  - Algorithms extract the RK from a received echo, given parameters of transmitted sonar signal

*Demonstrated on recorded data from various sonars prior to current program

MIRK is a Demonstrated Solution with Potential for Active Sonars

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- Frequency: 20 kHz – 500 kHz

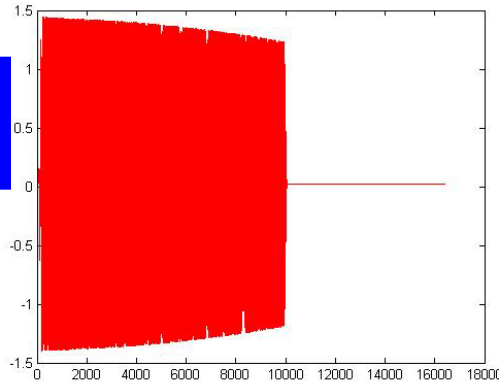
  Frequency agnostic; but sufficient time bandwidth product required
- Variety of environments
  - Very shallow to deep water
  - Fine sand to cluttered with rocks and ridges
- Multiple Targets
  - Bottomed and volume mines
  - Submarines
    - Bottomed or moving slowly
    - Air or water filled (bottomed)

Distinguishes target from both natural and man-made non-targets

The Inverse Problem

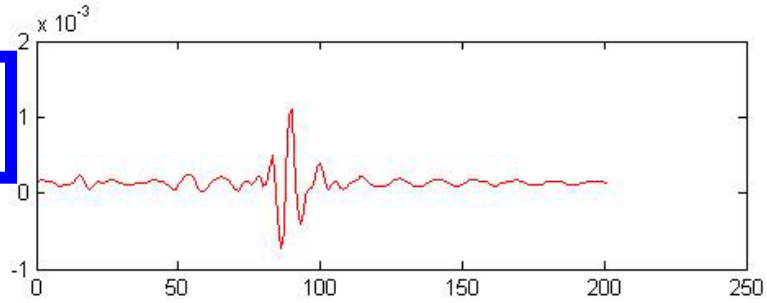
Given the input signal (s) and the scattered or output signal (f), find the Reflectivity Kernel (K)

Input

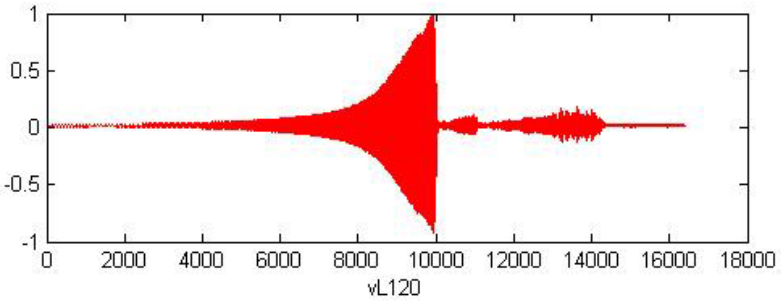


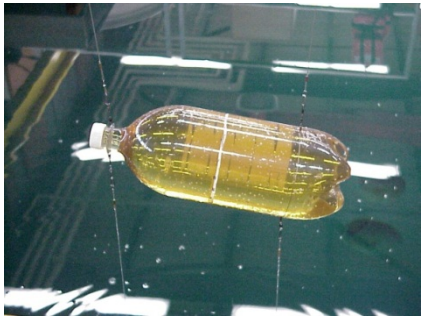
$$f(t) = \int K(t - t')s(t')dt' + noise$$

Kernel

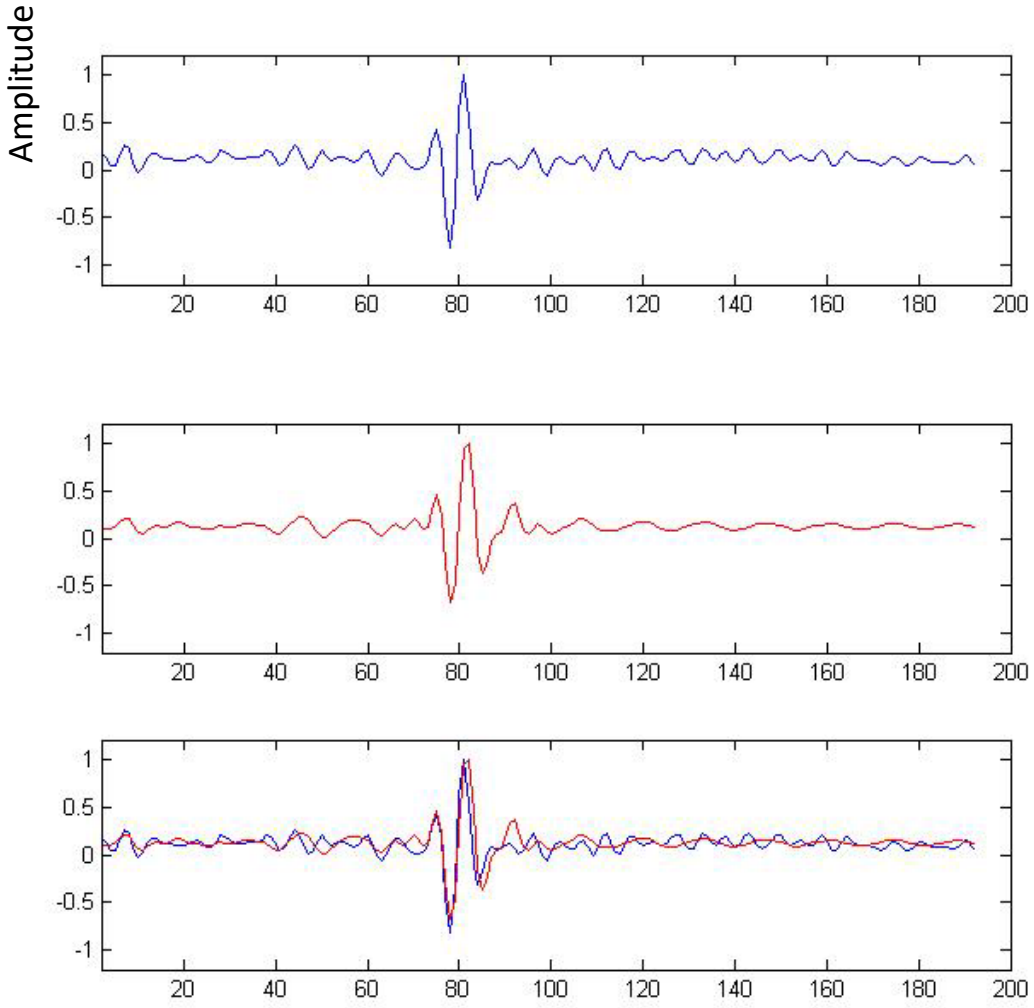


Output





Resulting Kernel Structure For Same Material



Different shapes, same material

Kernel nearly identical

Resulting Kernel Structure For Different Materials

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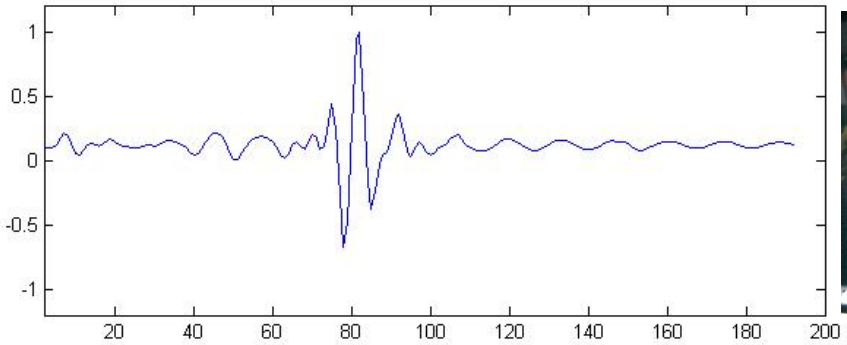
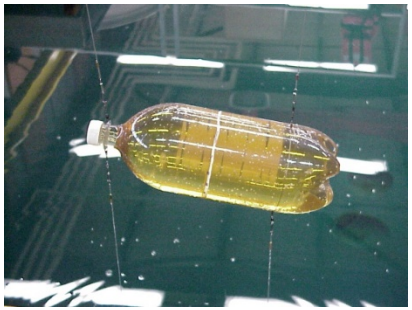
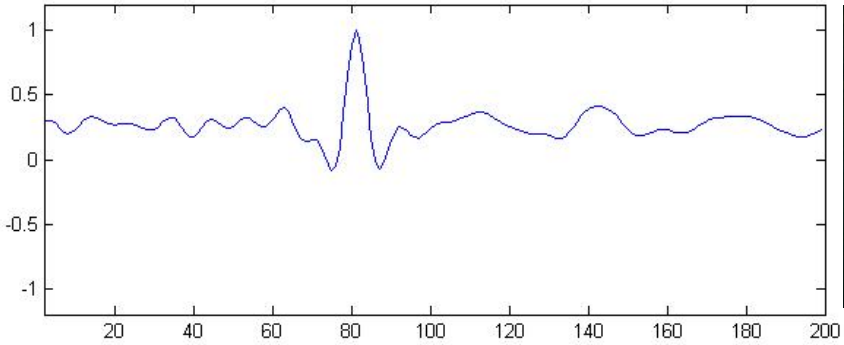
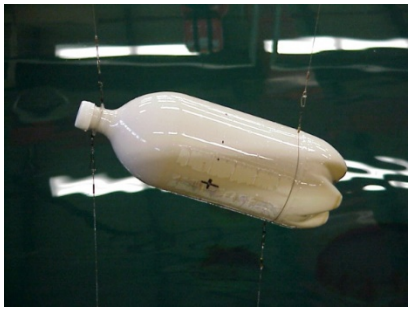
Different materials, same shape

MIRK derived kernel structurally different

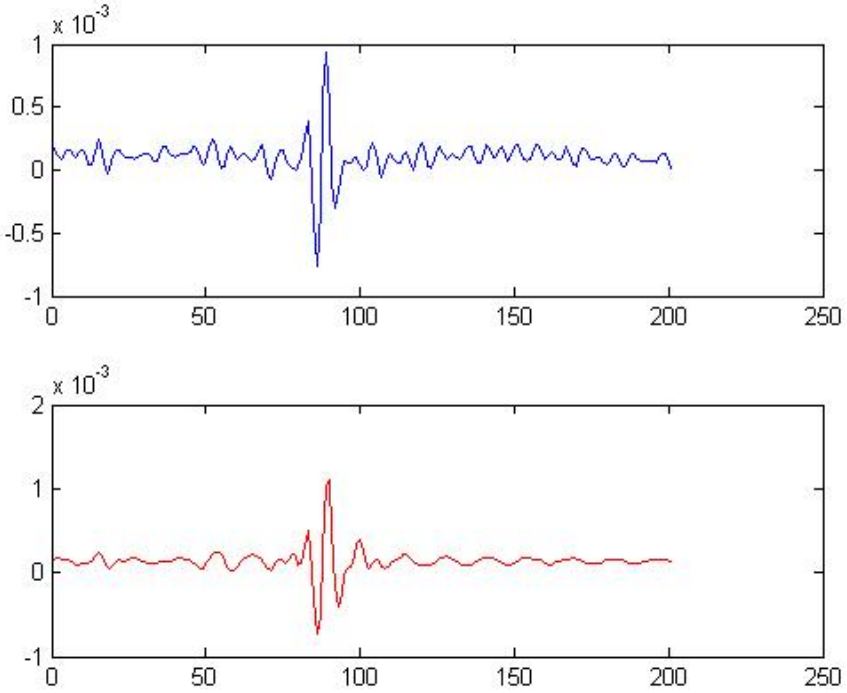


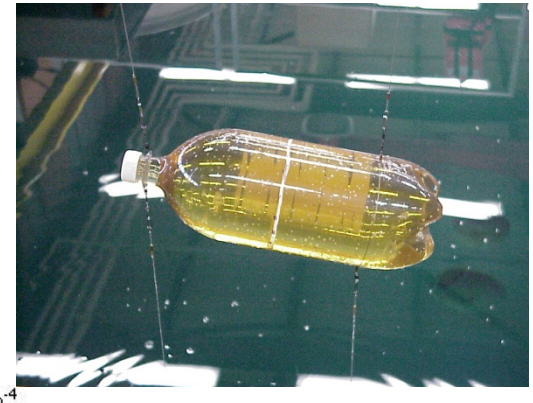


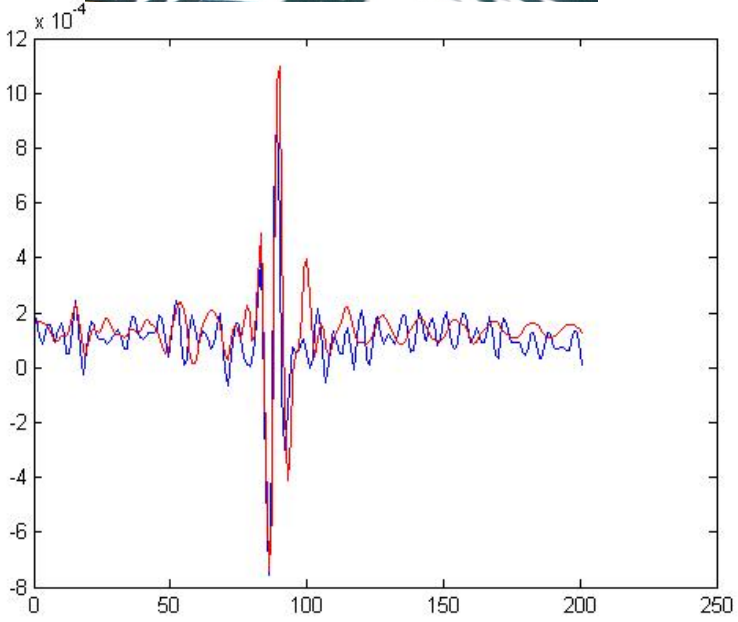




Different Interrogating Signals

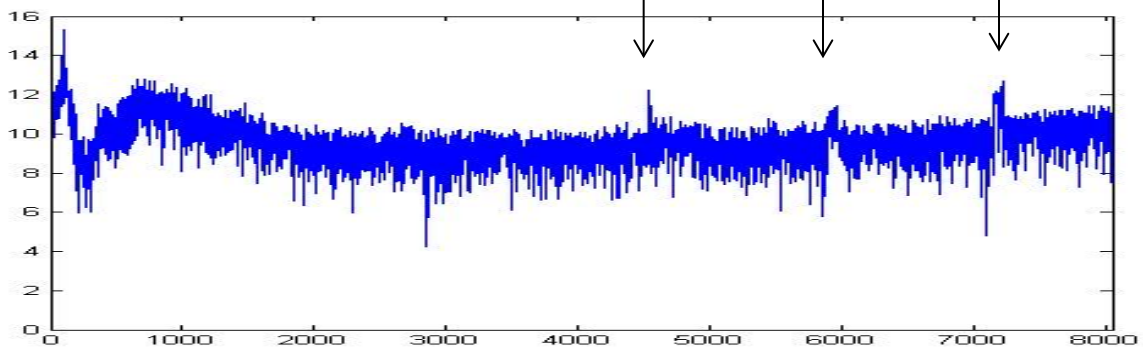




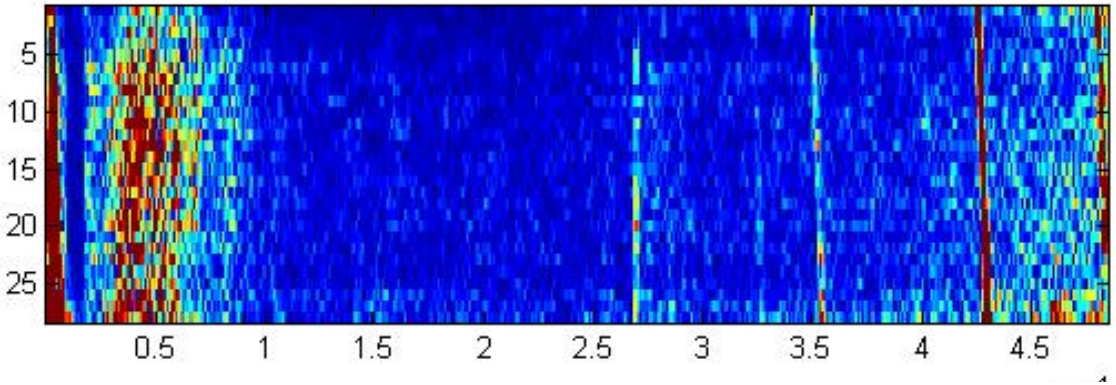


MIRK RK analysis indicates the same kernel structural response for different signals incident on the same material

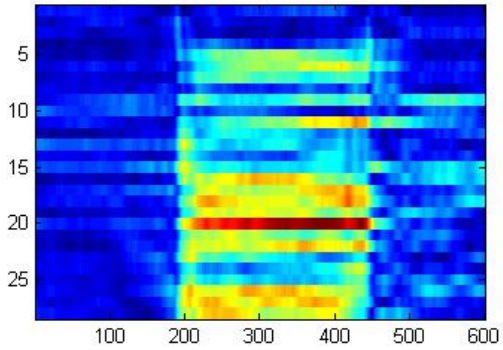
MIRK Detection / Classification Example

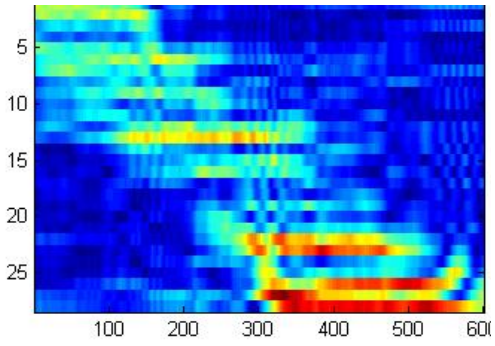


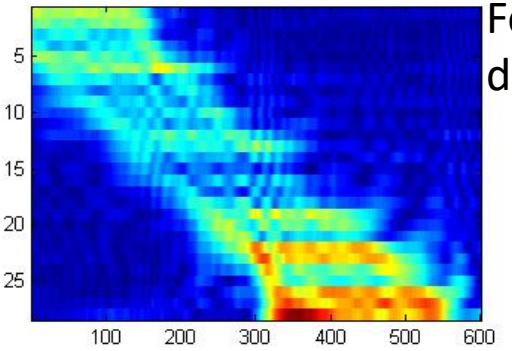
Log of matched filter amplitude



MIRK feature map

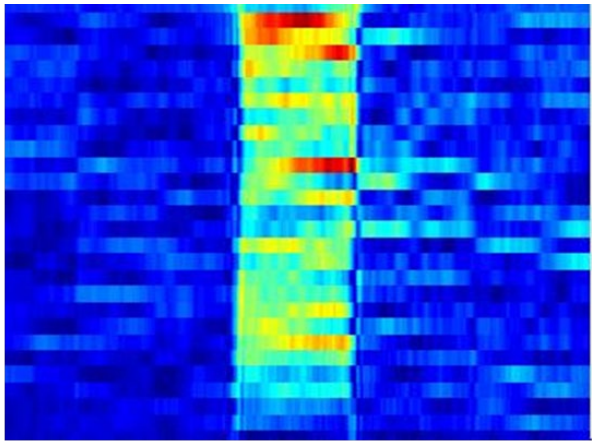
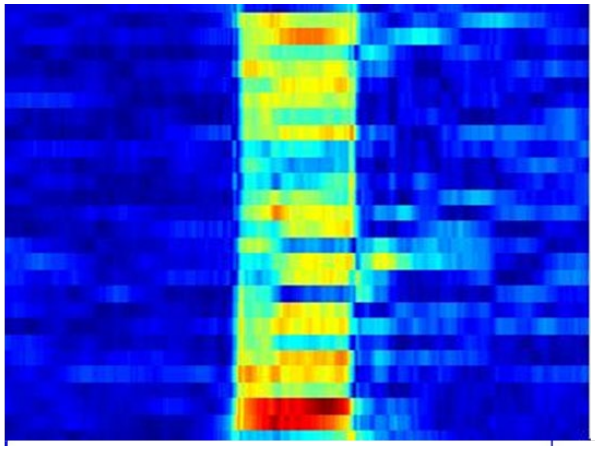
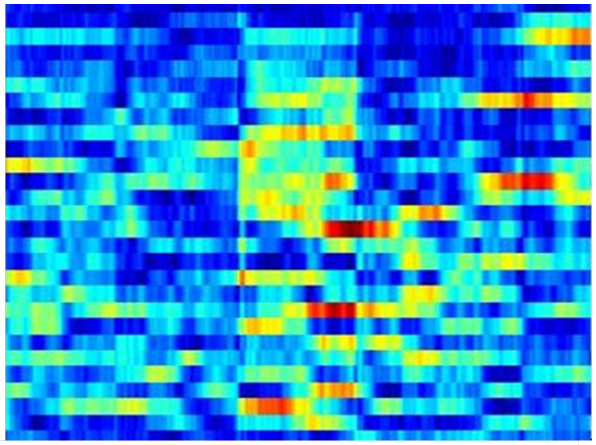




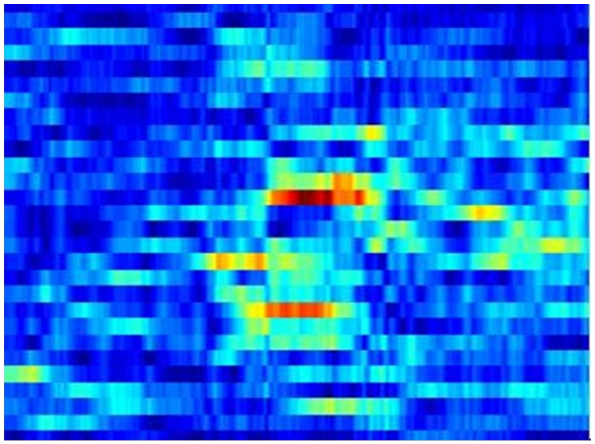
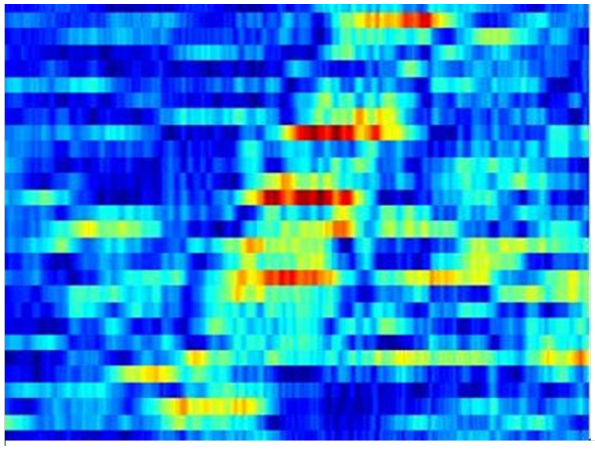
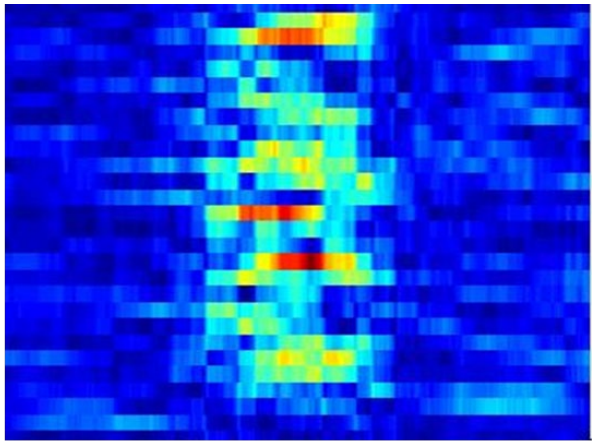


Featuregram detail

MIRK Classification Target v. Non-Target

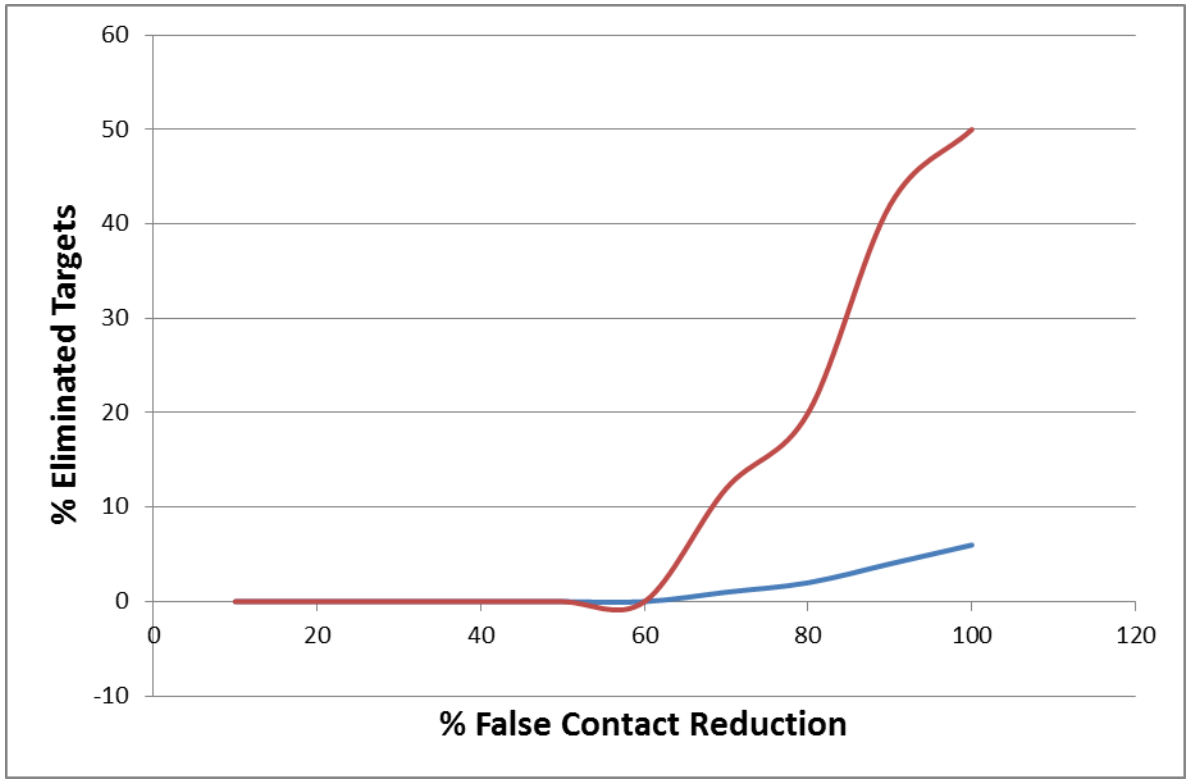




KNOWN TARGET

NON-TARGET

Notional MIRK Performance on Active Sonars



- Software only upgrade
- Relatively insensitive to frequency and waveform
- Discriminates out even high SNR false contacts

Performance Attributes

- Relatively insensitive to operating frequency
- Current fleet sonars provide adequate bandwidths
- Robust in low and high signal to noise ratio (SNR) echo returns
- Operates in parallel with existing detect/classify functions
- Can be inserted into many active sonar systems with only a software impact:
  - Torpedo
  - Submarine
  - UUV
  - Surface ship

  - MIRK will provide active sonar single pass mine/submarine detection/classification on returns over their operational listening range without need of imaging or multiple looks.

MIRK State Of Development

- Proven USAF Program of Record (Material Identification-Synthetic Aperture Radar (MISAR)) TRL-9
- Demonstrated sonar capabilities TRL-5
  - Naval Undersea Warfare Center (NUWC) analysis after MIRK processing of torpedo sonar data showed highly enhanced performance PROVEN via post processing torpedo exercise data
  - MIRK processing of MCM sonar data shows excellent results on false target rejection without missing true targets PROVEN via post processing MCM exercise data
  - MIRK processing of submarine sonar data shows improved capability against bottomed targets PROVEN: during Rapid Innovation Fund (RIF) project via post processing submarine sonar exercise data. DoD website:

"Provides the warfighter the capability to reliably detect bottomed submarines and mines in real time with fewer false alarms, significantly increasing the fleet's ability to defeat Anti-Access/Area Denial (A2/AD) threats"

Source: http://www.defenseinnovationmarketplace.mil/RIF.html

FY 2011 cell F41

MIRK State of Development

- Existing SBIR Phase II
  - Currently working on demonstration of improved performance of MCM ship sonar TRL-6
  - Demonstrated additional false alarm reduction with no loss of true targets on a modern FLS

- Operates in parallel with existing detector/classifier to provide augmenting target discrimination to decision architecture

Transition to Fleet

- Demonstrated significant performance improvement in laboratory environment
- Ship installation of laptop MIRK processing in parallel with ship sonar system processing
  - Demonstrate real-time significant performance improvement
- Integrate MIRK into ship combat system

Prometheus Business Approach

- Successfully complete SBIR Phase II
- SBIR Phase III: Assist Navy with tailored sonar system software integration and improvement
  - MCM systems
  - ASW systems
  - UUV detection systems
- Work with Navy labs, prime contractors, and other small businesses to demonstrate on additional systems; integrate

Prometheus: About Us

- Prometheus Inc. is a small, woman-owned software research and engineering firm founded in 1983 that specializes in applied mathematics.
- Our goal is to develop algorithms and software that avoid the need for hardware changes and exploit the capability of emerging hardware to reduce system costs while improving performance.
- Prometheus Inc. brings together academic and industry experts in: • acoustics • antenna array design • applied probability • digital filtering • Fourier analysis • optimization • pattern recognition • radar • scattering theory • signal processing • sonar • waveform design

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