Receiver Exploiting Variability in Estimated Acoustic Levels
Project Review – 16 Sept 2008

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REVEAL Long Range Goals

• Develop a signal processing structure that exploits environmental knowledge by incorporating signal and noise predictions.

• Use this SP structure to develop improved detectors and classifiers which remain robust to variable and random signal and noise.

• No specific system application, but focus on passive sonar and frequency ≤ 1 kHz.

• Train the future generation of ocean acousticians and signal processors.
• Since FY05, the project goal has been to work at the interface between OA and SP in order to apply and transition OA products to SP algorithms.
Compute signal and noise parameter statistics (also called prior statistics or training data)

Ocean acoustic models and knowledge

Passive beamformed sonar data

M-ary detector or classifier

• Estimated Ocean Detector (composite Likelihood Ratio)
• Kullback-Leibler divergence (et. al.)
• Bayesian (histogram) filter
Classification using discriminant functions
Typical problem

The signal is affected by propagation through the ocean, and we have knowledge and models for the oceanic properties and processes that affect acoustic propagation.

Our approach is to use Monte Carlo simulation to obtain many realizations of the signal from statistically-valid realizations of the environment in order to classify the signal source.
Composite LR

Consider observation \( r = s(\theta) + n \). A composite Likelihood Ratio (LR) incorporates statistical knowledge of random parameter \( \theta \):

\[
\Lambda(r) = \frac{p(r \mid H_1)}{p(r \mid H_2)} = \frac{\int_{-\infty}^{\infty} p[r \mid H_1, \theta] p(\theta \mid H_1) d\theta}{\int_{-\infty}^{\infty} p[r \mid H_2, \theta] p(\theta \mid H_2) d\theta}
\]

Since the noise is additive, the likelihood function is the pdf of the noise:

\[
p[r \mid H_1, \theta] = p[r - s(\theta) \mid H_1, \theta] = p_n(r - s(\theta) \mid H_1)
\]

If the noise is Gaussian, the likelihood function is then:

\[
p_n(r - s(\theta) \mid H_1, \theta) = \frac{1}{\sqrt{2\sigma_1^2}} \exp \left\{ -\frac{[r - s(\theta)]^2}{2\sigma_1^2} \right\}
\]
and the Likelihood Ratio (LR) is:

\[ \Lambda(r) = \frac{\int_{-\infty}^{\infty} \exp \left\{ - \frac{(r - s_1)^2}{2\sigma_1^2} \right\} p(\theta | H_1) d\theta}{\int_{-\infty}^{\infty} \exp \left\{ - \frac{(r - s_2)^2}{2\sigma_2^2} \right\} p(\theta | H_2) d\theta} \]

The Estimator-Correlator (EC) provides an expression for the LR in the more general case where the noise pdf belongs to the exponential class. Jeff Ballard formulated the EC for Gaussian signals in FY07 and sinusoids in FY08.

Neglecting noise

When the noise is negligibly small, the likelihood function becomes

\[ p(r | H_1, \theta) = p(r - s(\theta) | H_1, \theta) \approx \delta[r - s(\theta)] \]

and the Likelihood Ratio is then

\[ \Lambda(r) = \frac{\int_{-\infty}^{\infty} p[r - s(\theta) | H_1, \theta] p[s(\theta) | H_1] d\theta}{\int_{-\infty}^{\infty} p[r - s(\theta) | H_2, \theta] p[s(\theta) | H_2] d\theta} \approx \frac{p[s(\theta) | H_1]}{p[s(\theta) | H_2]} \]

We have made this assumption in applying the composite LR to the 1996 Strait of Gibraltar and Swellex-96 data, respectively.

The Bayes filter is an alternative to the LR in which we use Bayes rule

\[ p(r | H_i, \theta) p(H_i | \theta) = p(r, H_i | \theta) = p(H_i | r, \theta) p(r | \theta) \]

to convert the likelihood function to the posterior pdf

\[ \frac{p(r | \theta, H_i) p(\theta | H_i)}{p(r | \theta)} = p(H_i | r, \theta). \]

We select the hypothesis with the highest posterior probability.

The histogram filter is the discrete implementation of the Bayesian filter. Colin will compare a recursive histogram filter to the LR receiver.
Distance measures

- The Kullback-Leibler divergence (among others) provides a measure of the distance between two multidimensional surfaces, e.g. pdfs.
- Using a distance measure to classify signals:
  - Predict signal parameter pdfs for difference classes
  - Estimate signal parameters from observations; compute signal parameter pdfs from observations
  - Pick the class whose pdf is “closest” to the observed signal parameter pdf
- Brett will present his work on this approach
Noise whitening

• The EOD requires that the noise pdf belong to the exponential class. Not necessarily Gaussian. How to whiten or decorrelate?
• So-called “higher order whitening” has been investigated in the image processing literature.
• Whitening is closely related to distance measures and to compressive sampling.
• Dr. Bose will present his work.

Predicting signal parameter pdfs

- Rough surface PE acoustic propagation model obtained from Rosenberg (APL/JHU); based upon Range-dependent Acoustic Model (RAM), but adds capability for acoustic propagation with time- and spatially-varying rough surface.
- We want to determine if this simulation can predict surface interaction effects on signal frequency and amplitude pdfs.
- Jeremy Joseph will present his work.
REVEAL FY08 Talks

  - Culver: “Likelihood func. & signal param. pdfs for sonar signal processing”
  - Joseph: “Effect of rough surface on received signals”

- **Apr 08 PSU College of Engr. Research Symposium (CERS)**
  - Jemmott: “Passive sonar source classification based on received signal amplitude variation statistics”

  - Bissinger: “Application of statistical methods in uw signal classification”
  - Joseph: “Effects of volume and boundary variability on the statistics of received signal frequency”
  - Culver: “Detection and classification using the Estimated Ocean Detector”

- **Distributed Detection and Est. Workshop (VA Tech, July 08)**
  - Bissinger: “Statistical Distance Based Signal Classification”
  - Culver: “Detection and classification using the Estimated Ocean Detector”
  - Jemmott: “Passive Sonar Model-Based Source Location Classification”
  - Joseph: “Effect of rough surface on received signals”

  – submitted to IEEE J. Oceanographic Engr. Dec 07
  – Comments received June 08
  – Manuscript revised and resubmitted Sept 08

R.L. Culver and H.J. Camin (Dependence of probabilistic acoustic signal models on statistical ocean environmental models”
  – Comments received May 08
  – Manuscript under revision; will re-submit by 30 Sep 08
Planned FY09 Talks and Papers

• Present at Asilomar (Oct 08), CISS (Mar 09), and UASP (Oct 09) signal processing meetings.
• Present as ASA (Nov 09) and (May 09)
• Publish papers on:
  – depth classification using the Swellex-96 data
  – higher order whitening
  – application of distance measure to uw acoustics
  – predicting uw acoustic signal parameter statistics
**REVEAL Project**  
**FY09 Plans**

- Apply classifiers to South Florida range data
  - Bottom-mounted line arrays
  - Surface ships and a towed, submerged source
- Move from high SNR to moderate SNR cases
  - Incorporate noise whitening for EOD
  - Robustness of distance measures and histogram filter
- Address correlation in extracted parameter values
- Incorporate the rough surface RAM simulation into the signal processing architecture
REVEAL Project

Ocean environment
- ocean models
- In-situ measurements

Monte Carlo simulation

acoustic propagation model

signal realizations

Classifier

Detection/classification decision

Signal parameter pdf's (MaxEnt method)

- sonar data
- noise pdf
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- environ. realizations
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Colin and Brett
REVEAL Project

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Dr. Bose

Signal parameter pdf's (MaxEnt method)
The REVEAL Project focuses on ocean models, in-situ measurements, and signal parameter probability density functions (pdf's) using the MaxEnt method. It involves Monte Carlo simulation and acoustic propagation modeling for signal realization. Sonar data and noise pdfs are inputs to the classifier, which outputs detection/classification decisions.