Passive Sonar Tracking on Multibeam Intensities

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See also ADM002078., The original document contains color images.
Sonar Processing Architectures

- Beamformed Intensity Data
  - Broadband Peak Pick Threshold & Beam Interpolate
    - Data Association
      - Tracking
  - Narrowband Peak Pick Threshold & Beam Interpolate
    - Tracking
      - Signature Building
  - Energy Superposition Modeling
    - Hybrid Broadband Narrowband Tracking
Intensity Data

Wide Targets, Increasing Intensity
Single Target Tracking Results

Wide Targets, Increasing Intensity
Estimated +/- 3 sigma overlaid on True Bearing
History

Modeling multibeam intensity as a histogram

- Perlovsky (c. 1991), Luginbuhl (c. 1999)
  - Interpreted cell-level sensor data amplitudes as histogram counts

- Streit (c. 2000), Streit (c. 2001)
  - Treated broadband intensity as a histogram
  - Modeled the superposition of energy from multiple targets using a mixture density
  - Extended histogram interpretation to frequency-azimuth domain

Direct energy superposition model

- Ristic, Farina, Hernandez (c. 2004)
  - Used a model of the sensor “point-spread function” to describe the distribution of energy across cells for tracking on image data
  - Applied a simple energy superposition model for developing a CRLB
  - No longer treating energy distribution as a pdf
Basic Model

• The basic superposition model

\[ Z_t = \{z_{t,1}, z_{t,2}, \ldots, z_{t,n}\}^T = C_t \mathbf{1}_n + \sum_{j=1}^{k} h(x_t^j) + \eta_t \]

• The augmented state

\[ X_t = \{ C_t, (x_t^1)^T, (x_t^2)^T, \ldots, (x_t^k)^T \}^T \]

\[ x_t^j = \{ \beta_t^j, \dot{\beta}_t^j, I_t^j, \gamma_t^j \}^T \]

• The target viewed through the sensor point spread function

\[ h(x_t^j) = \{ h_1(x_t^j), h_2(x_t^j), h_3(x_t^j), \ldots, h_n(x_t^j) \}^T \]

\[ h_i(x_t^j) = I_t^j \exp\left\{ -\frac{1}{2} \left( \frac{(\beta_i^j - \beta_t^j)^2}{\gamma_t^j} \right) \right\} \]
Estimation Algorithm

- Non-Gaussian noise
  - Not a problem for filtering, optimality sacrificed
  - Exponentially distributed frequency cells yield Gamma distributed broadband intensities, closely approximated by Gaussian

- Applied straightforward Kalman filter
  - Could use smoother, MLE or other
  - Relatively high dimensionality compared to traditional trackers
    - n-vector measurement
    - km+1 vector state

- Covariance decoupling
  - If prior covariance is decoupled, so is much of the processing
  - Kalman gain can be performed with a $km+1$ vs. $n$ dimensional inversion
  - Output covariance is fully coupled, but little performance penalty seen from extracting target blocks to form a decoupled prior for the next update
Intensity Data

Narrow Targets, Increasing Intensity
Single Target Tracking Results

Narrow Targets, Increasing Intensity

Estimated +/- 3 sigma overlaid on True Bearing
Intensity Data

Fixed Amplitude, Varying width Targets
Single Target Tracking Results

Fixed Amplitude, Varying width Targets

Estimated +/- 3 sigma overlaid on True Bearing

Intensity Processing

Peak Pick Processing - PDA
Improving SNR & Separability

Non-parametric model of target spectral characteristics:

\[ S_t^j = \{s_{t,1}, s_{t,2}, \ldots s_{t,k}\}^T \]

Outer product forms model of frequency-azimuth image:

\[ \text{FRAZ} = h_i(x_t^j)^T S_t^j \]

Parametric model of spatial location:

\[ h_i(x_t^j) = I_t^j \exp \left\{ -\frac{1}{2} \frac{(\beta_i^j - \beta_t^j)^2}{\gamma_t^j} \right\} \]

- Hold \( S_t^j \) fixed, estimate \( x_t^j \)
- Given estimate of \( x_t^j \), estimate \( S_t^j \) as a weighted average over beams, weighting based on \( h(x_t^j) \)
Summary

• Initialization requires detection, but tracking does not
• Superposition model results in an implicitly multitarget algorithm, no combinatorial problems
• Simple model admits simple processing
• Filter dimensionality is not a problem, simplifying approximations can make processing even simpler
• Provides reliable track bearing quality outputs
• “Self tuning”
• Tracks over-resolved targets without modification