Passive Sonar Tracking on Multibeam Intensities

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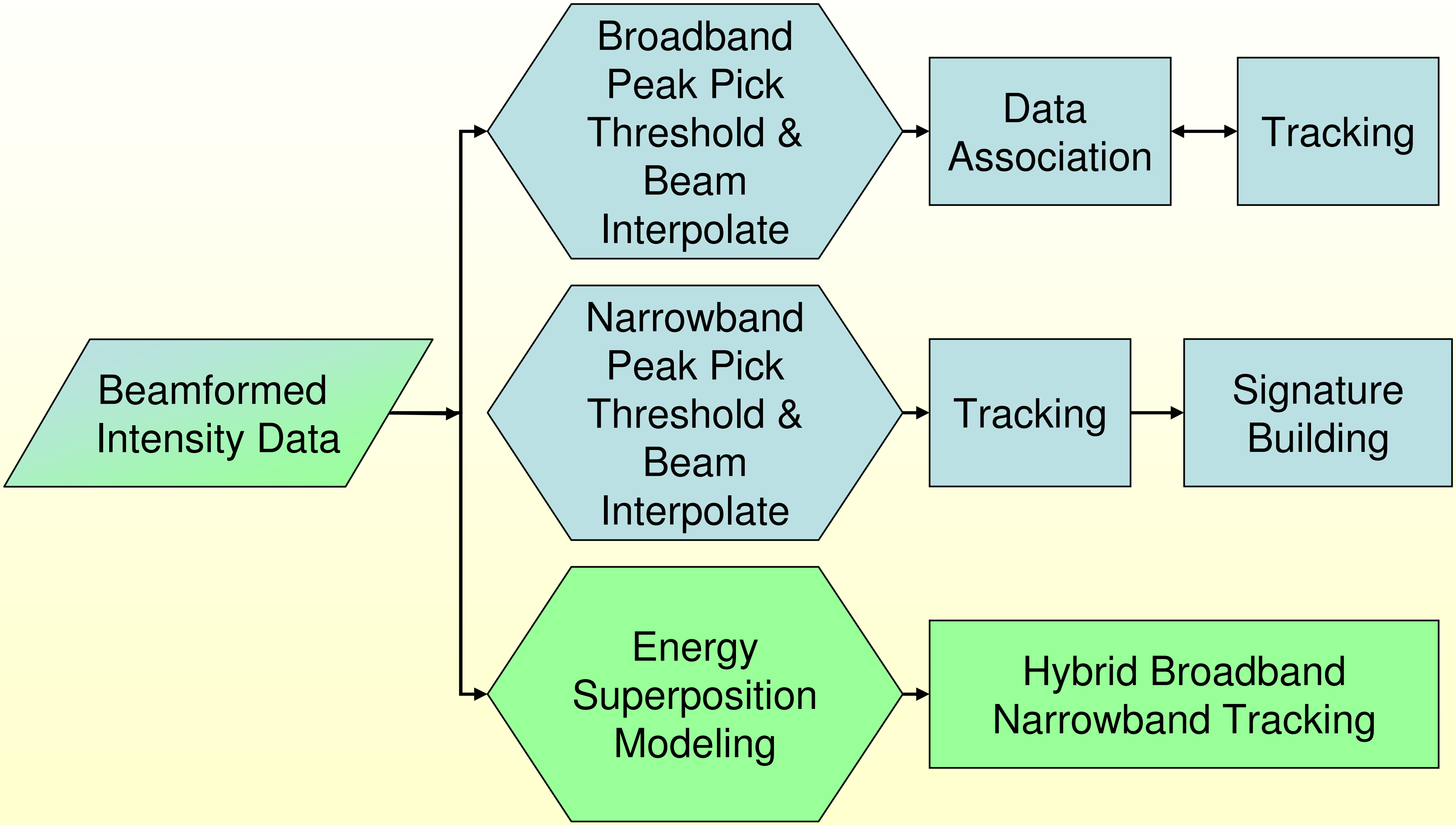
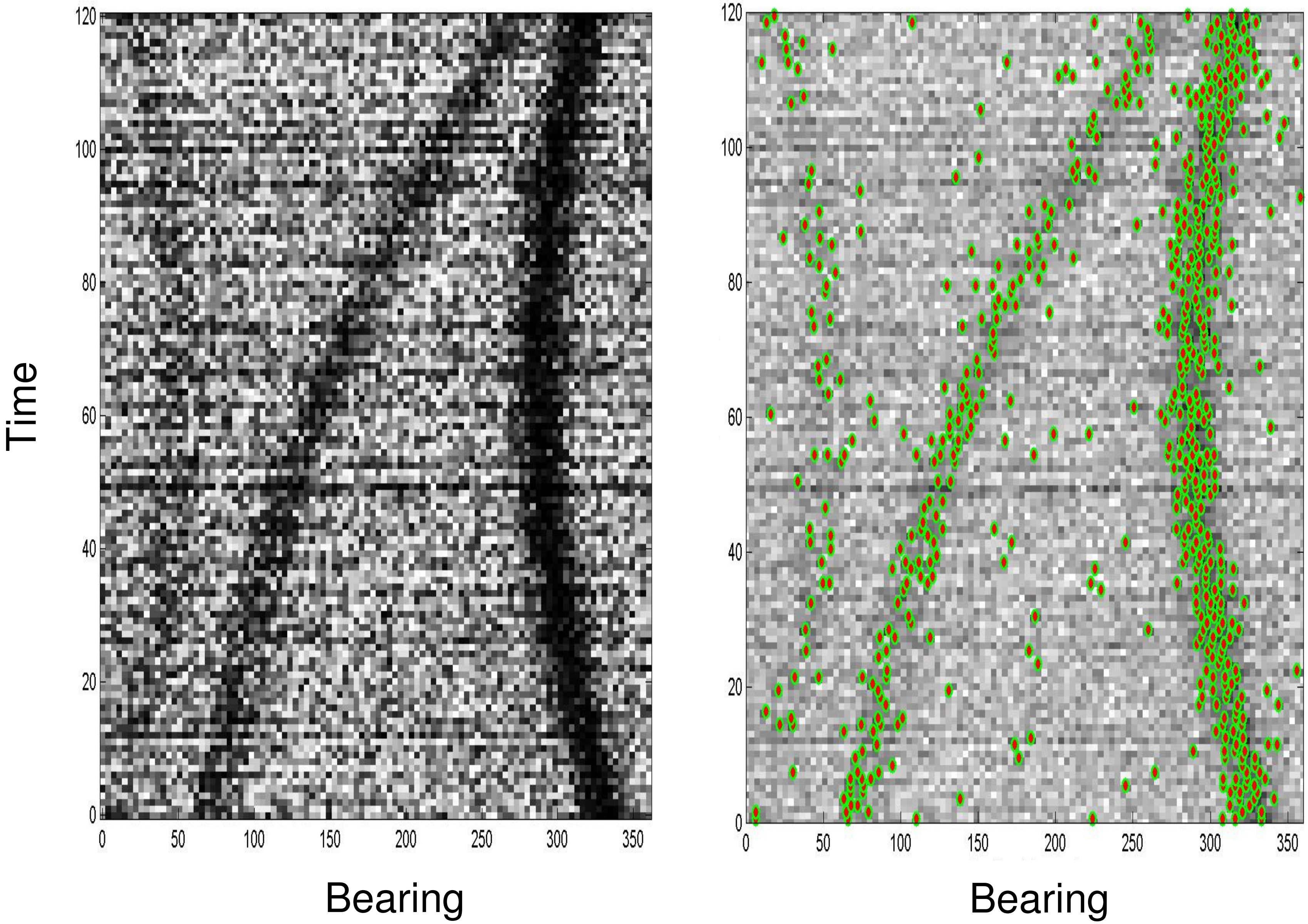
Sonar Processing Architectures



Intensity Data

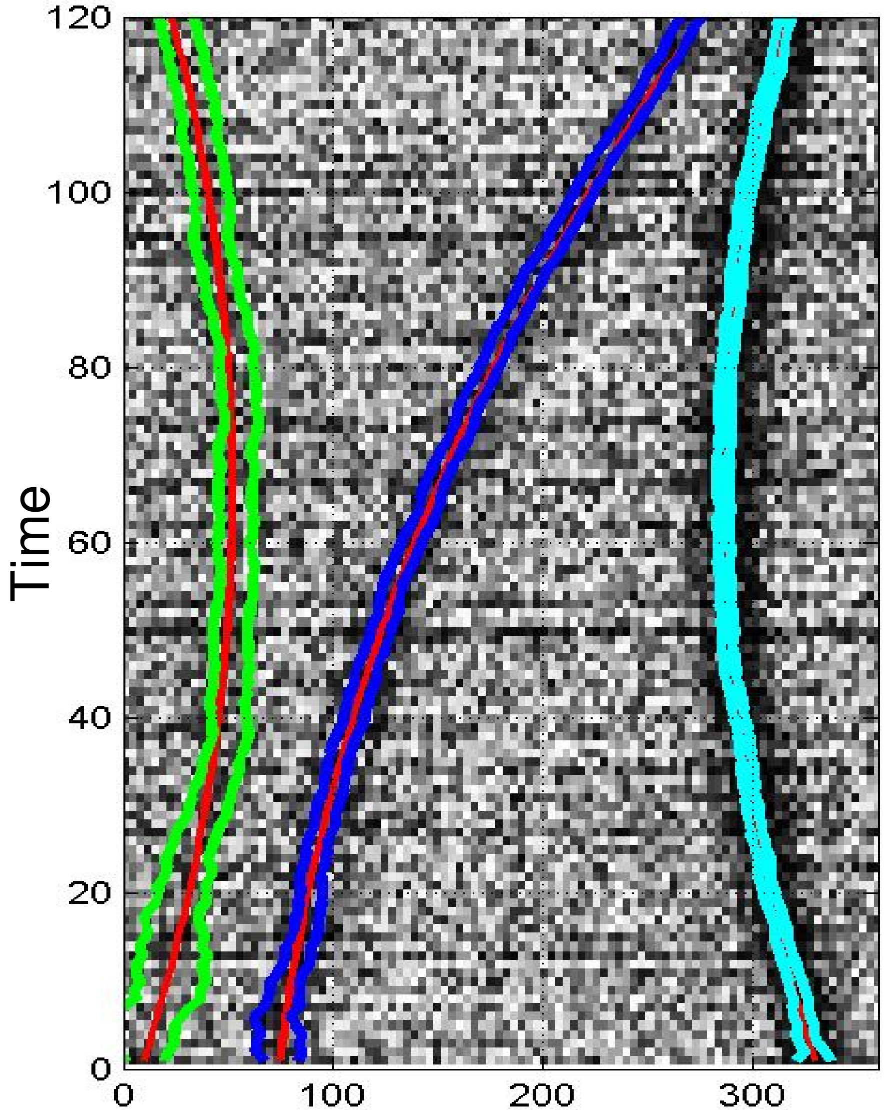
Wide Targets, Increasing Intensity



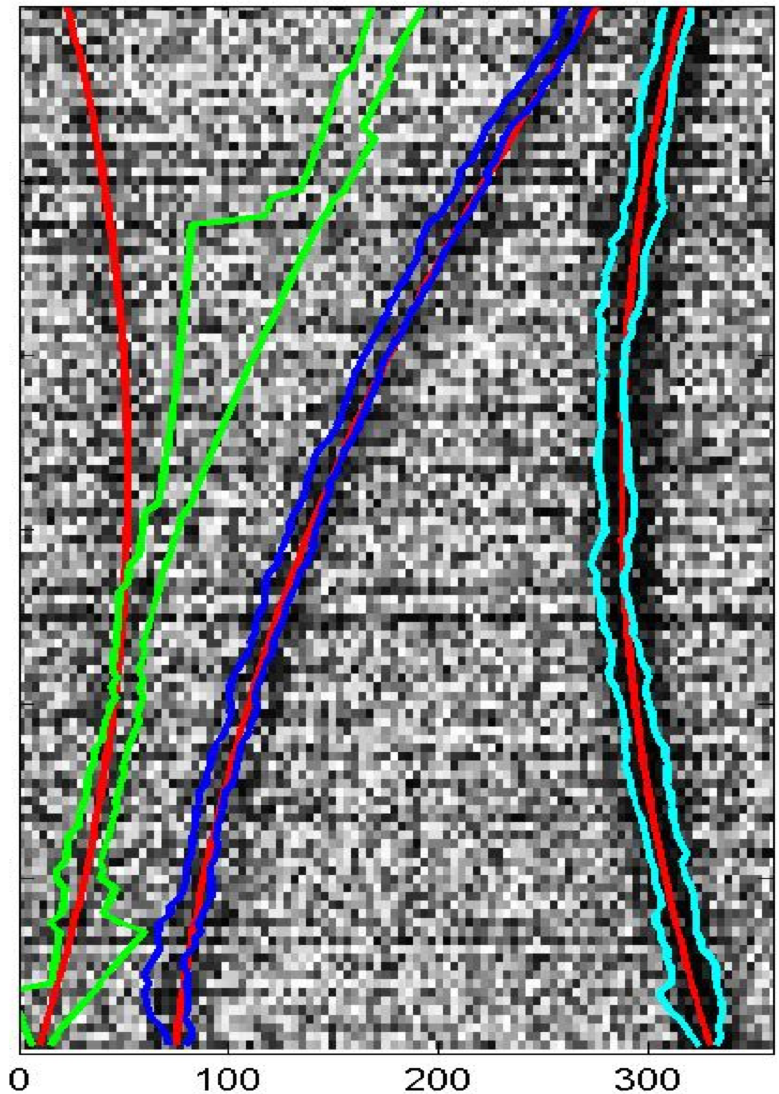
Single Target Tracking Results

Wide Targets, Increasing Intensity

Estimated +/- 3 sigma overlaid on True Bearing



Intensity Processing



Peak Pick Processing -PDA

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**

$$Z_t = \{z_{t,1}, z_{t,2}, \ldots, z_{t,n}\}^T \quad = \quad C_t\,\underline{1}_n + \sum_{j=1}^{k} \underline{h}(x_t^j) + \underline{\eta}_t$$

- **The augmented state**

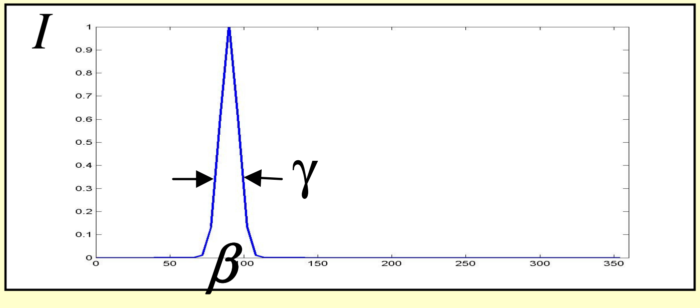
$$X_t = \{\, C_t, (x_t^1)^T, (x_t^2)^T, \ldots, (x_t^k)^T \,\}^T$$

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

- **The target viewed through the sensor point spread function**

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

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

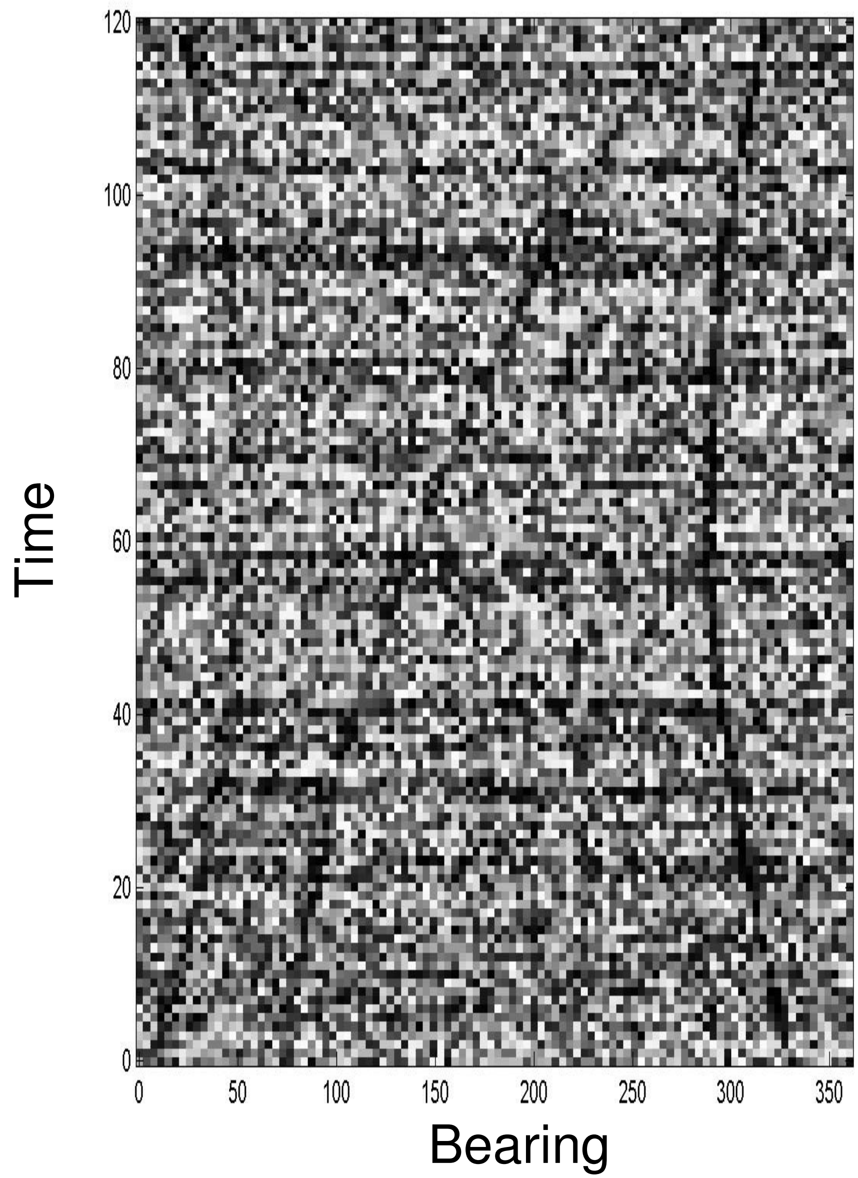


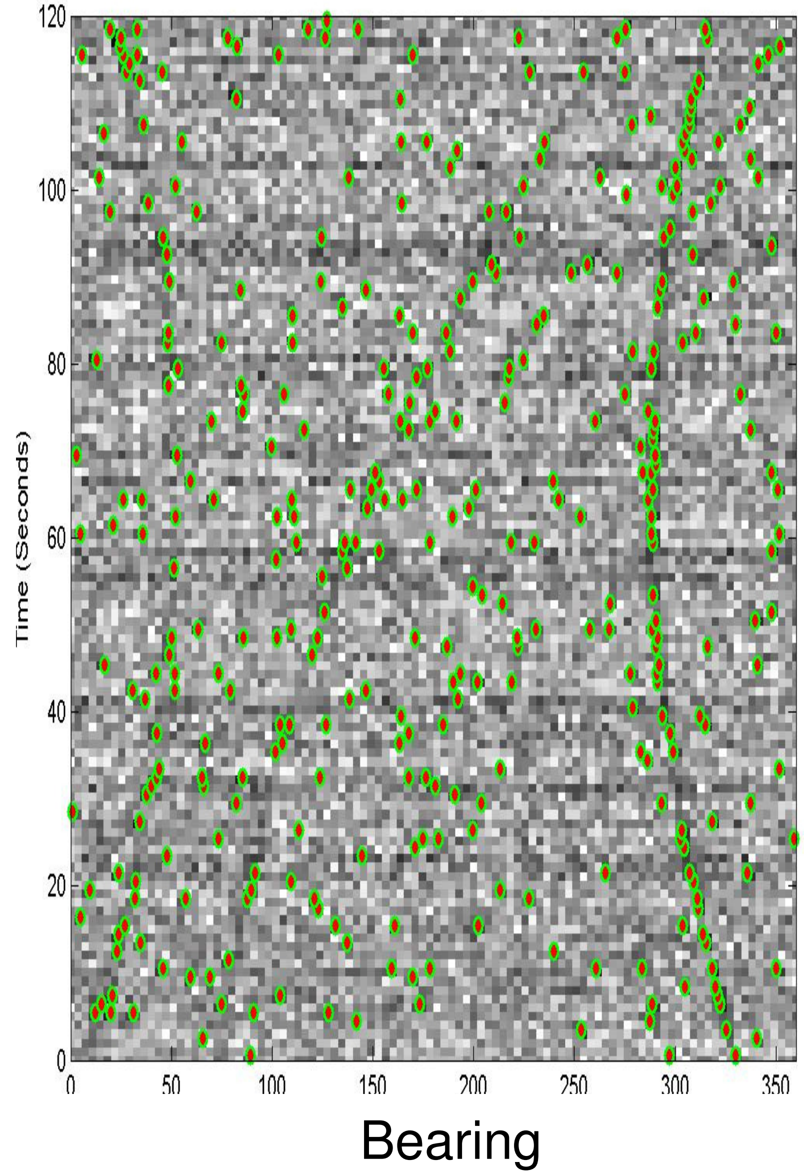
Estimation Algorithm

- 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

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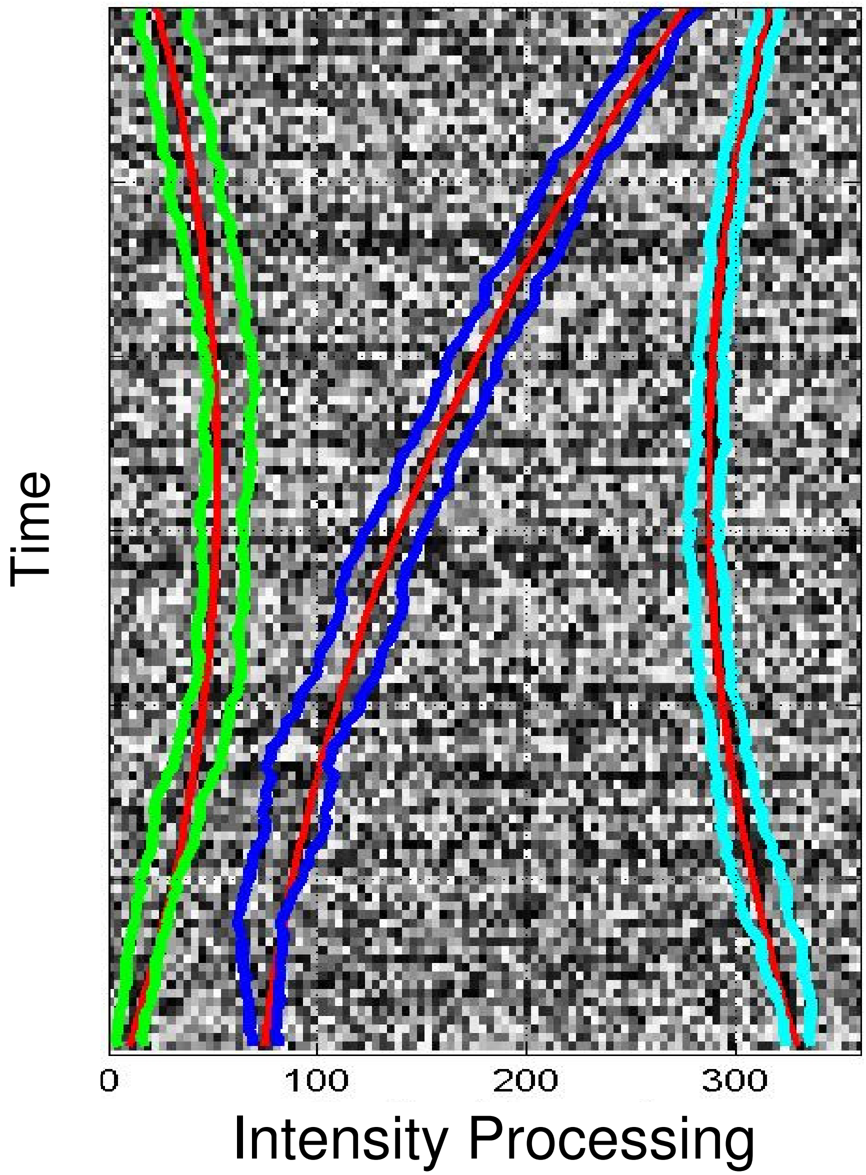
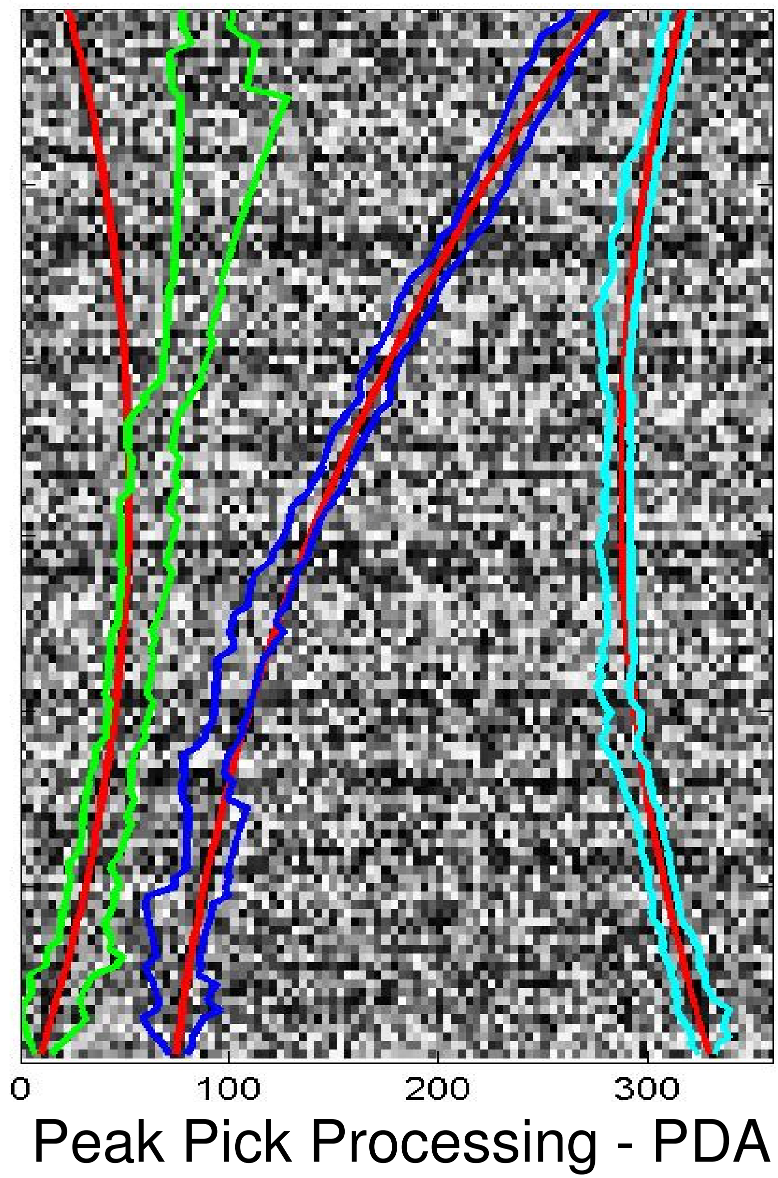
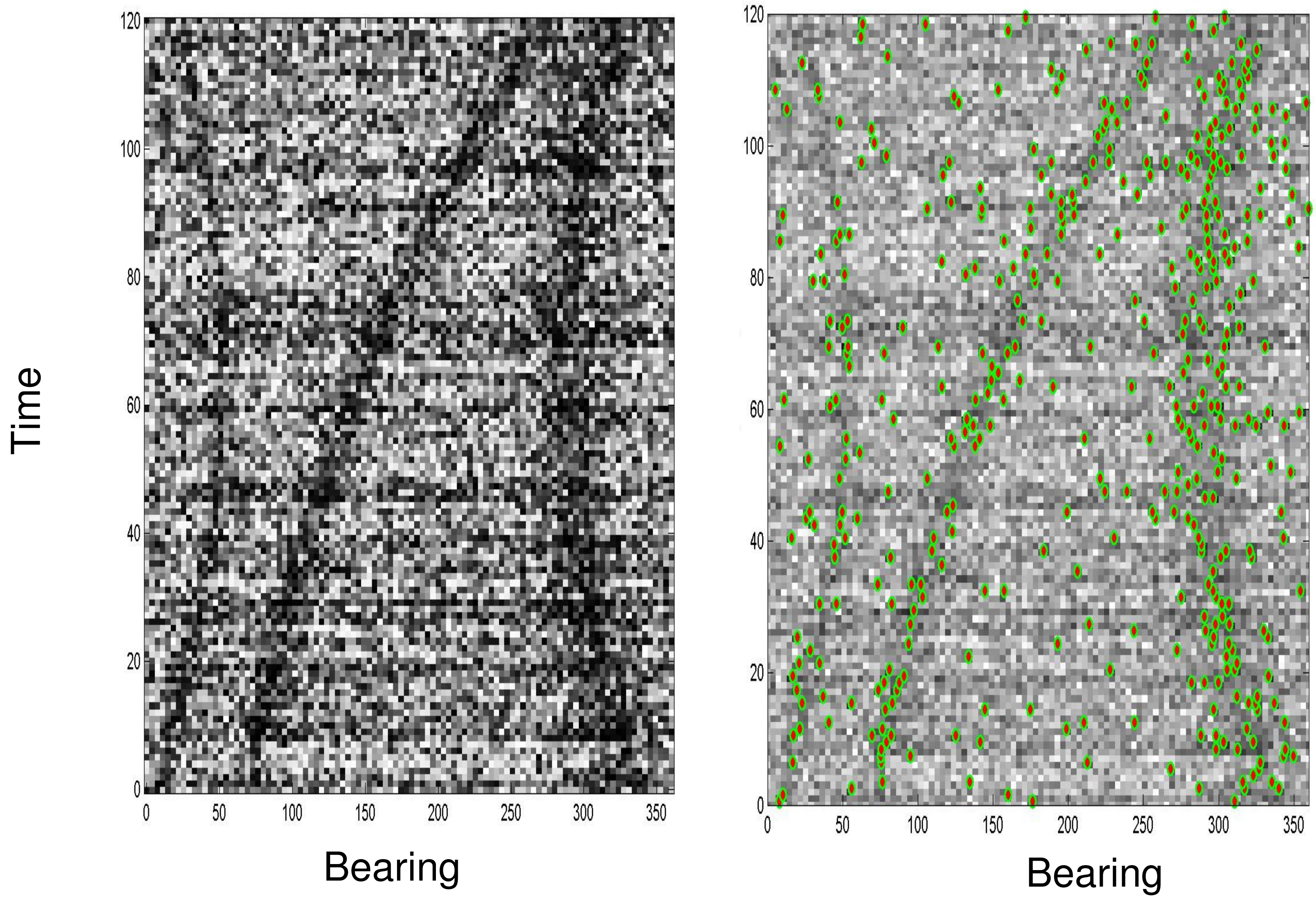




Intensity Data

Fixed Amplitude, Varying width Targets



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Fixed Amplitude, Varying width Targets

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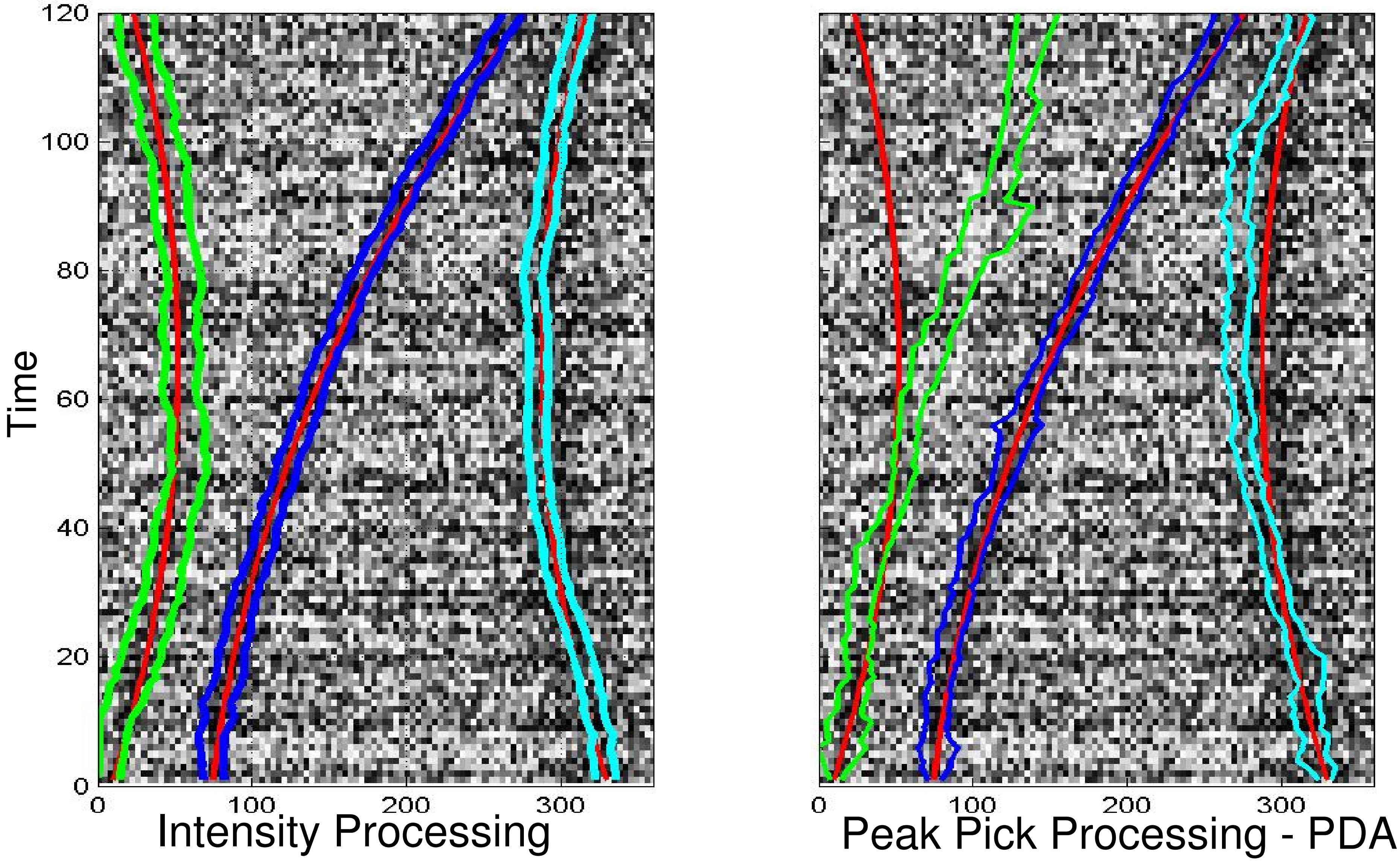
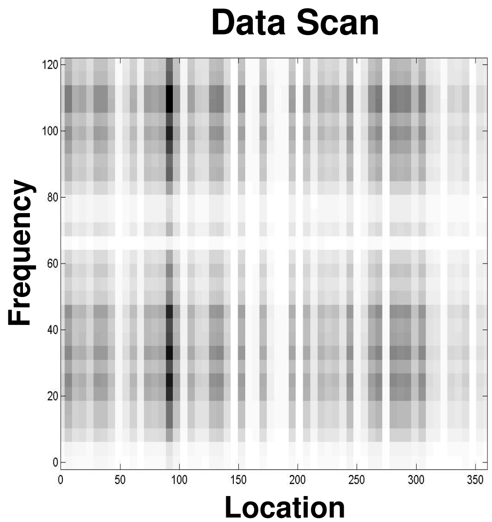
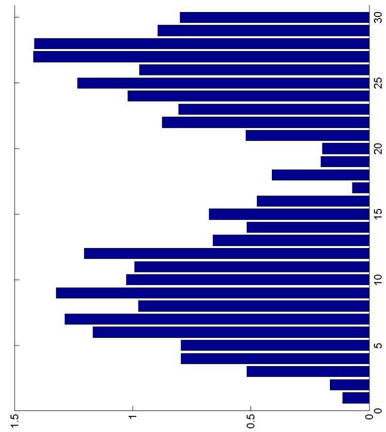
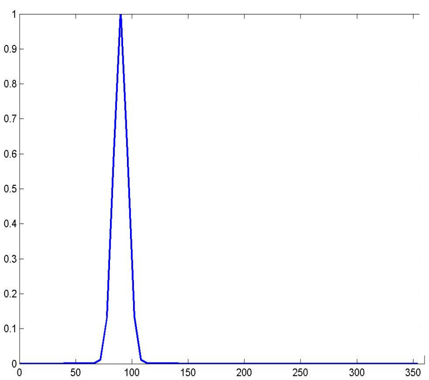


Improving SNR & Separability







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 :

$$\mathrm{FRAZ} = h_i(x_t^j)^T \ S_t^j$$

Parametric model of spatial location :

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

- Hold S^j fixed, estimate x^j
- Given estimate of x^j, estimate S^j as a weighted average over beams, weighting based on $h(x^j)$

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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