

Passive Sonar Tracking on Multibeam Intensities

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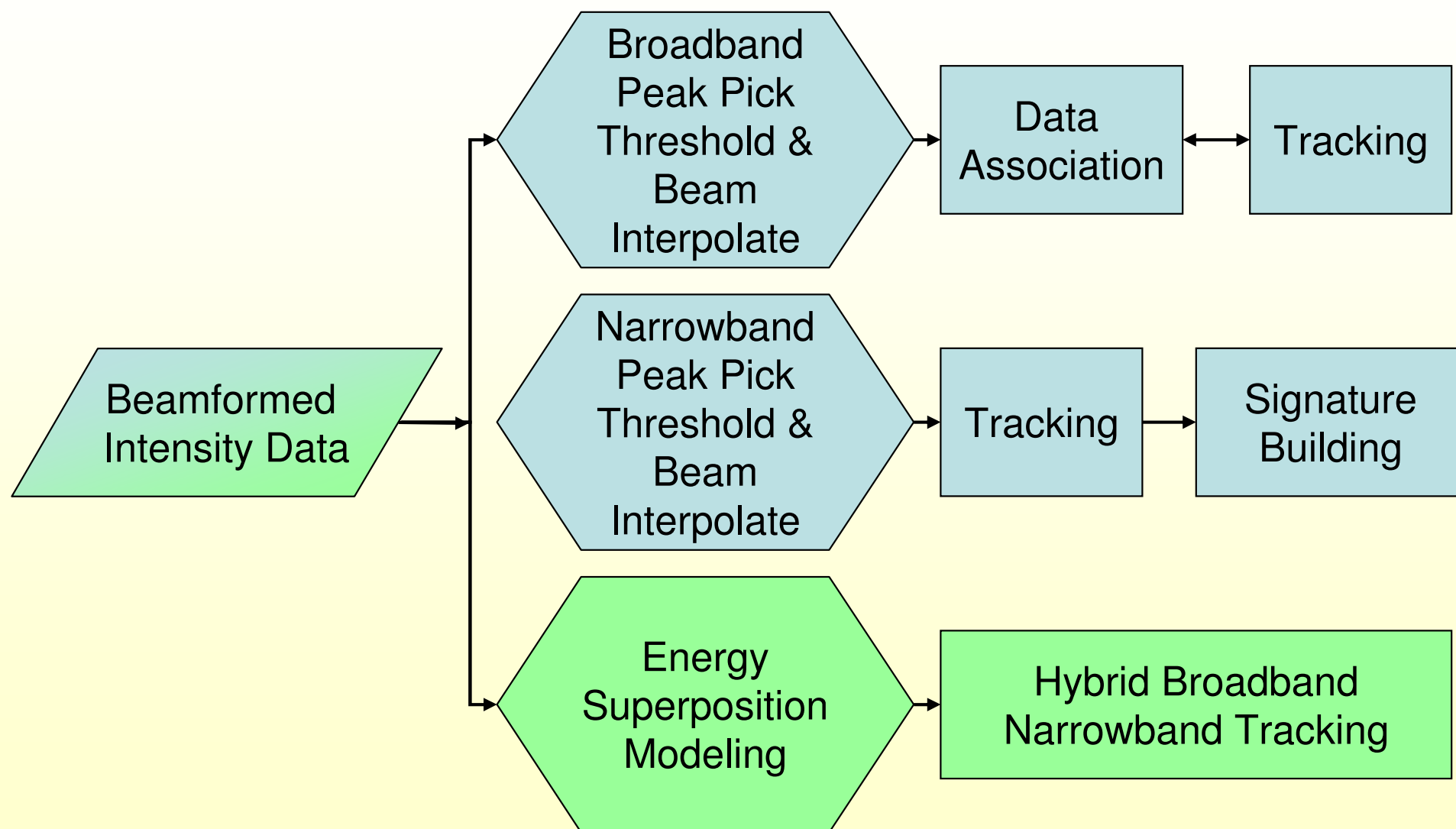
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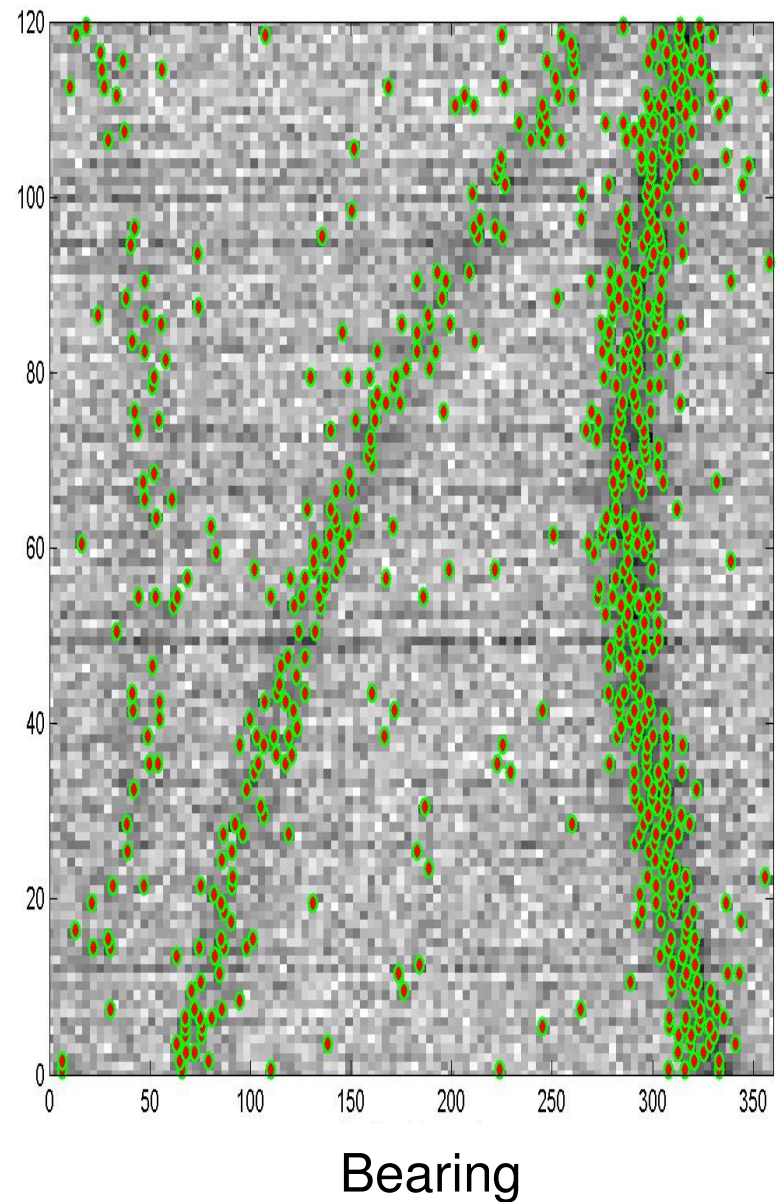
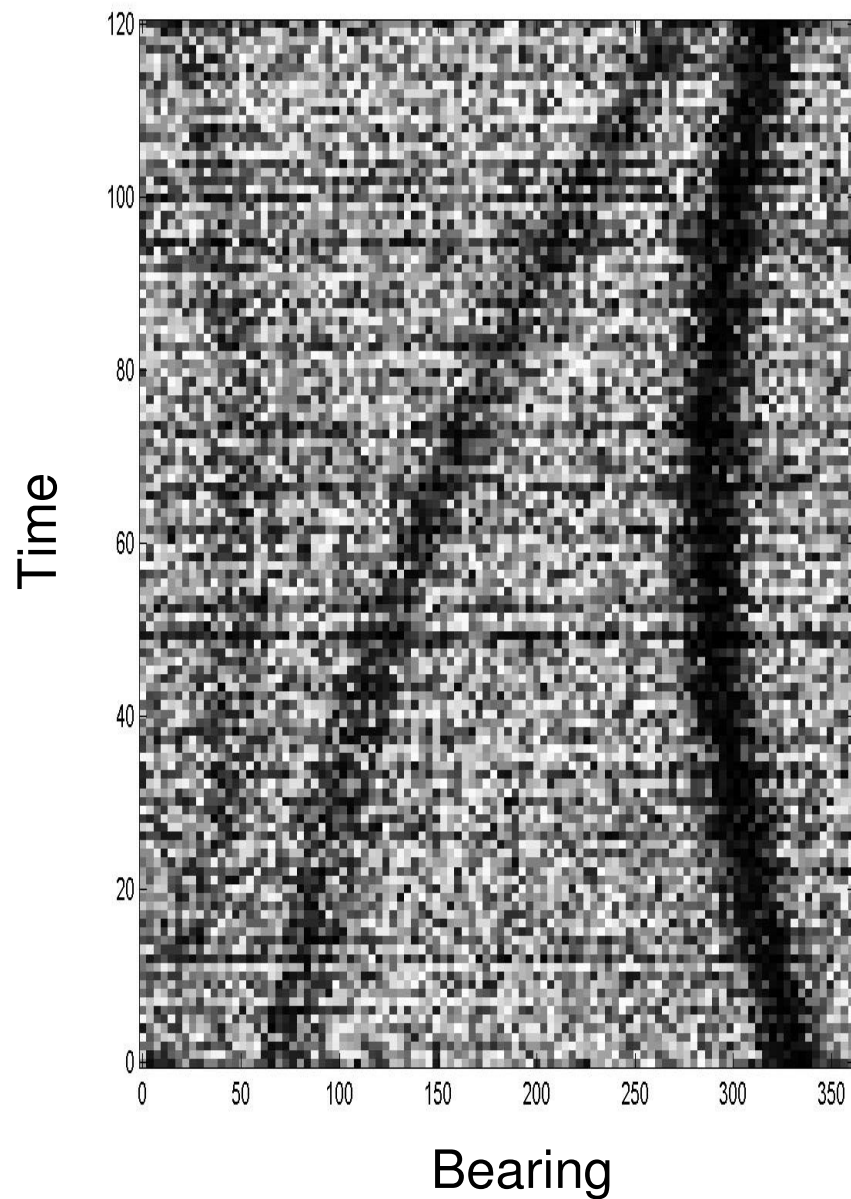
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Sonar Processing Architectures



Intensity Data

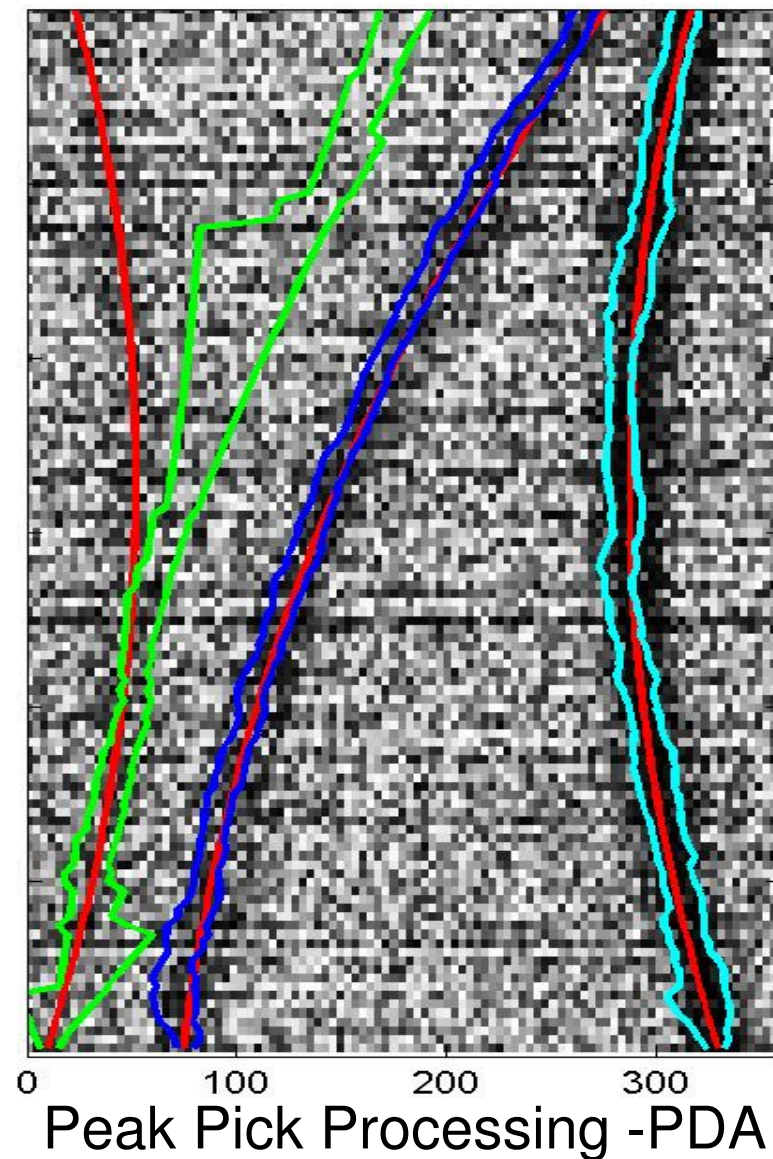
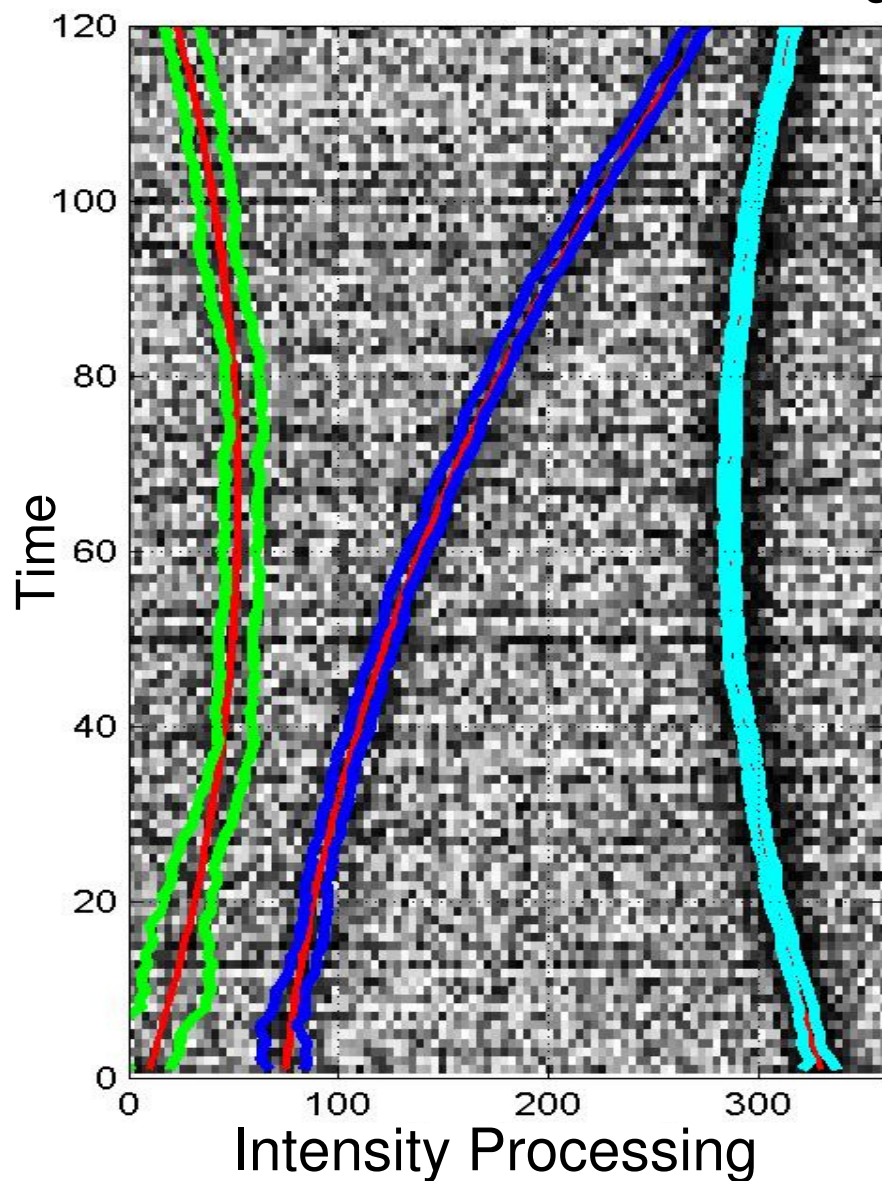
Wide Targets, Increasing Intensity



Single Target Tracking Results

Wide Targets, Increasing Intensity

Estimated ± 3 sigma overlaid on True Bearing



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

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

- The augmented state

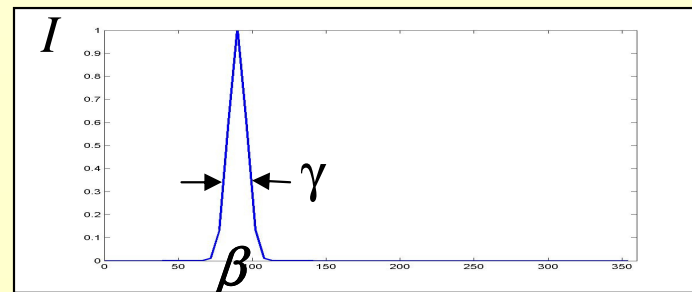
$$X_t = \{ C_t, (x_t^1)^T, (x_t^2)^T, \dots, (x_t^k)^T \}^T$$

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

- The target viewed through the sensor point spread function

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

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

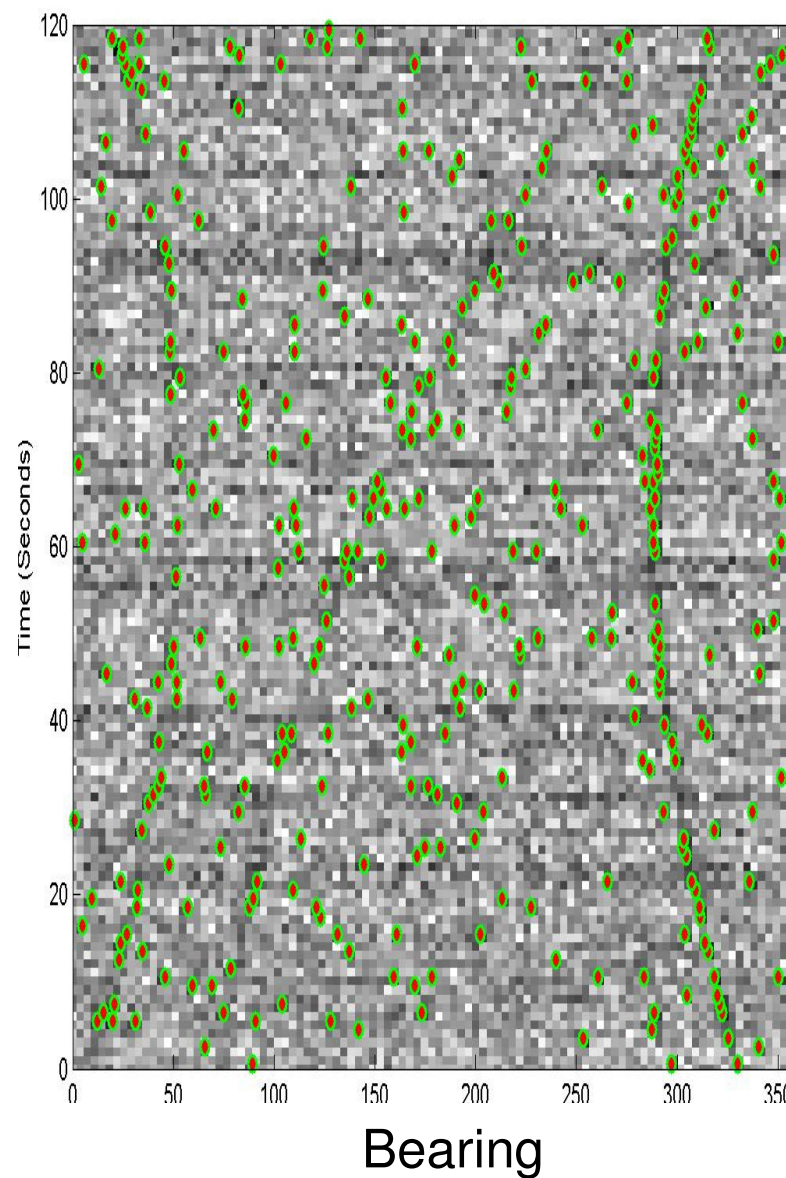
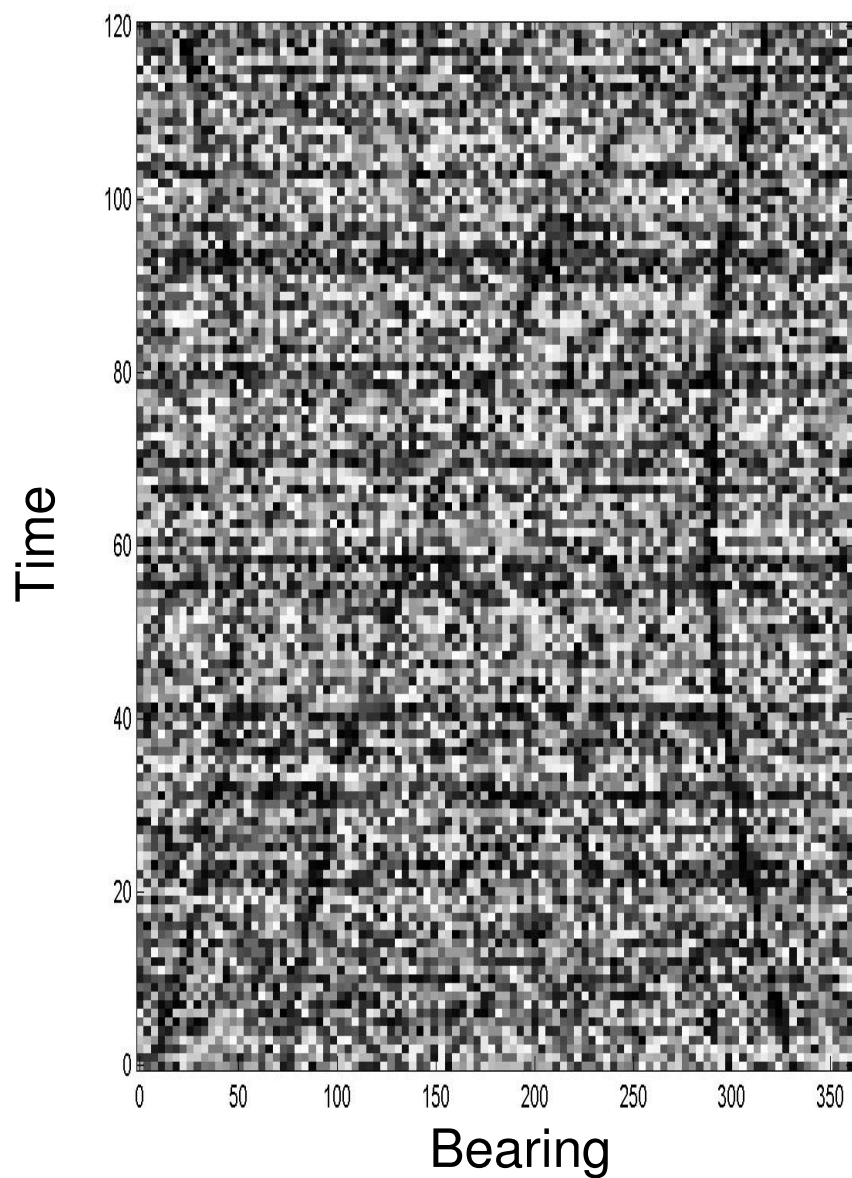


Estimation Algorithm

- **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

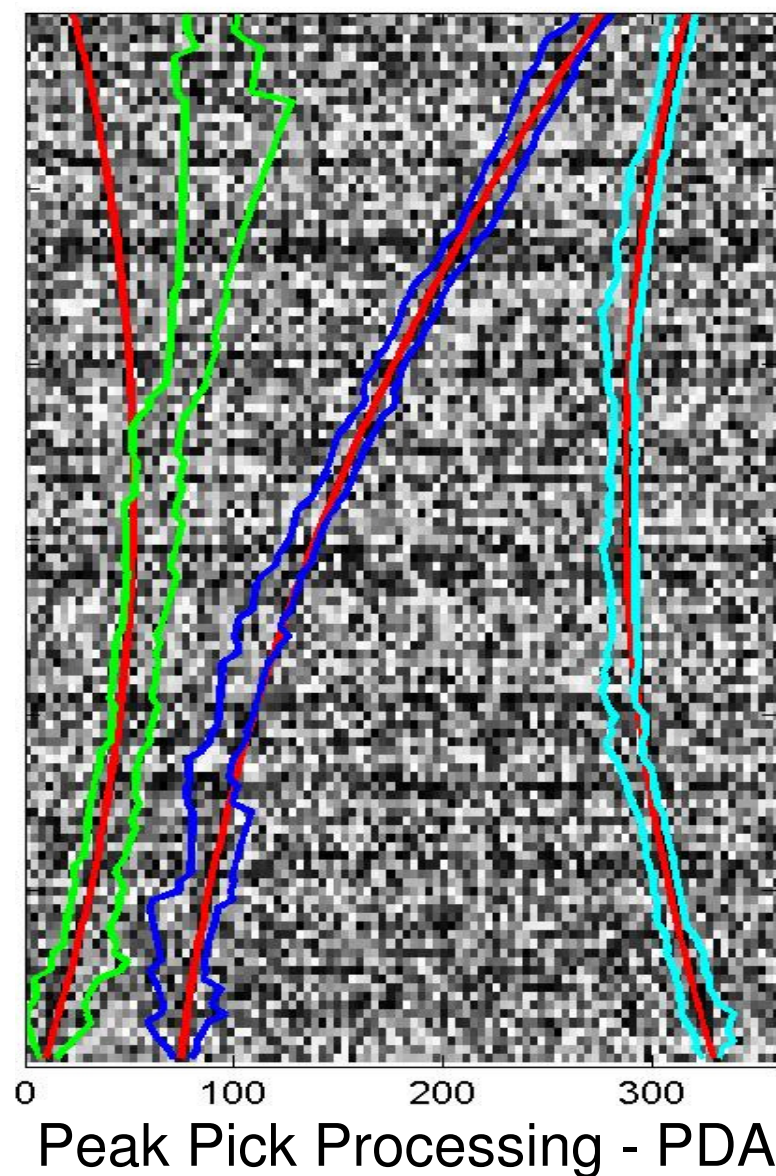
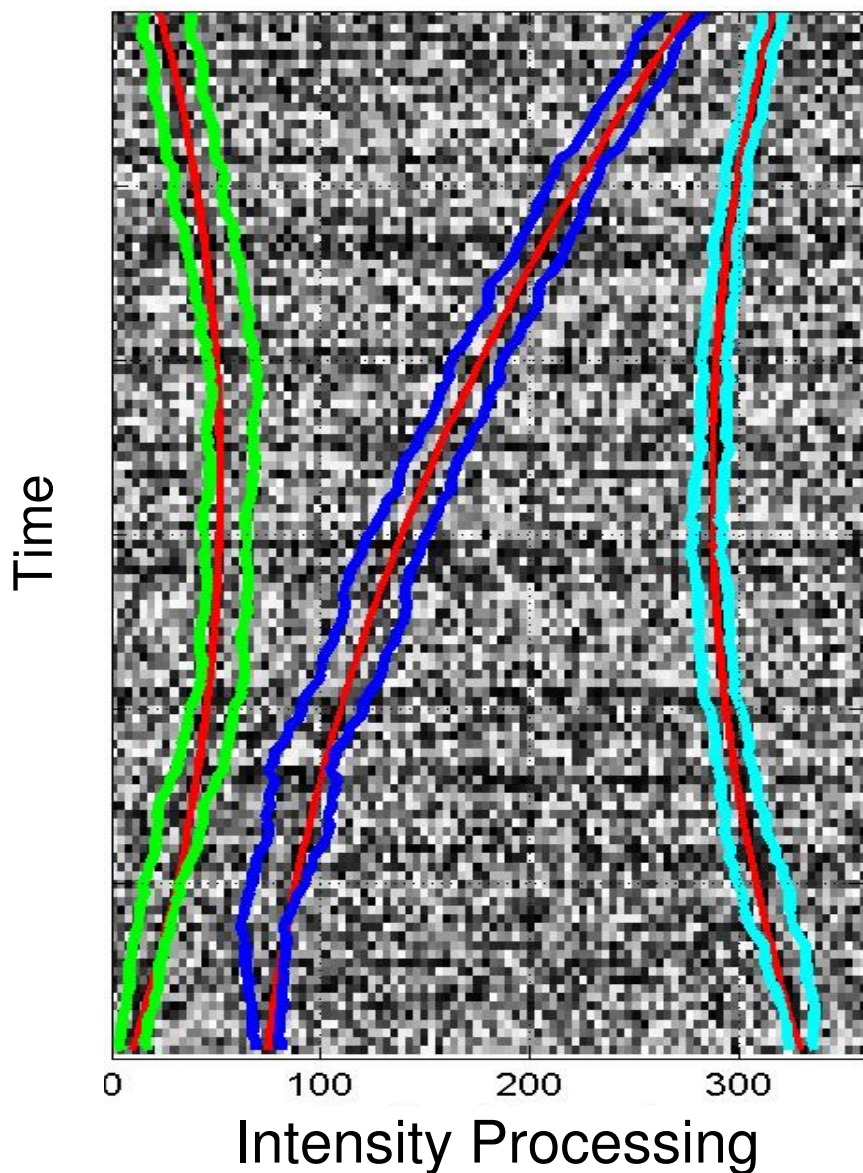
Narrow Targets, Increasing Intensity



Single Target Tracking Results

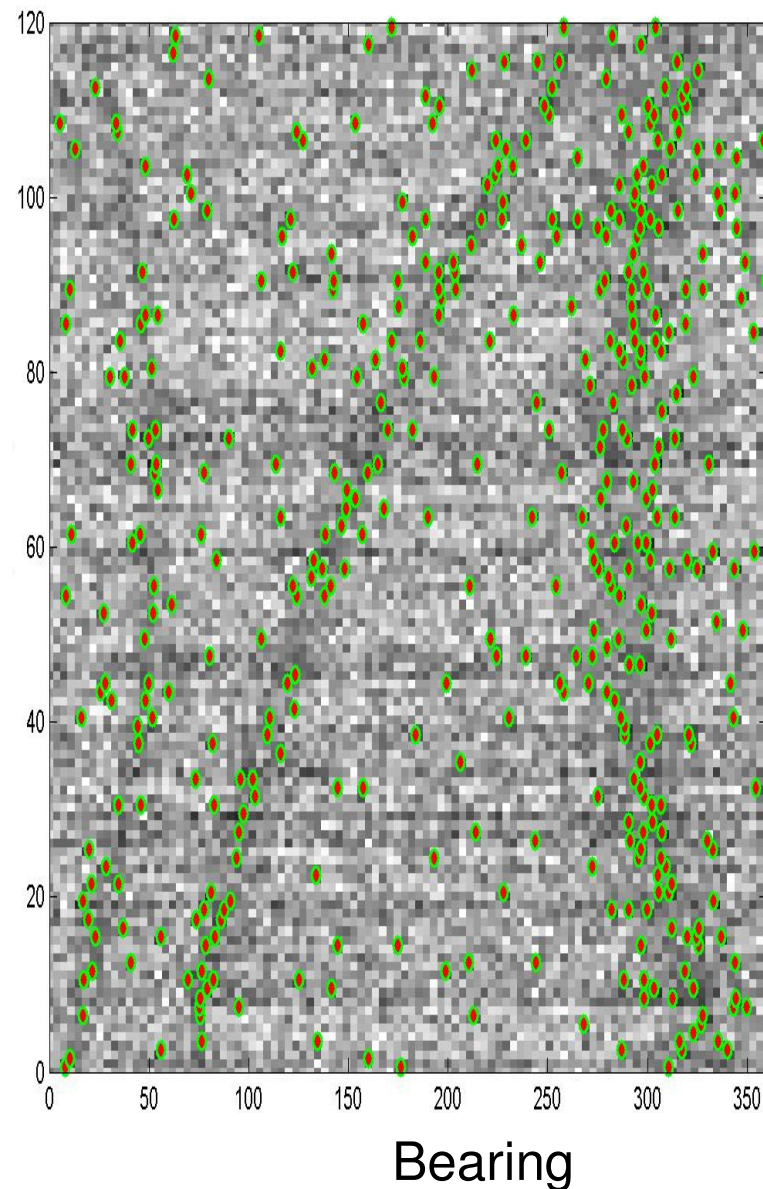
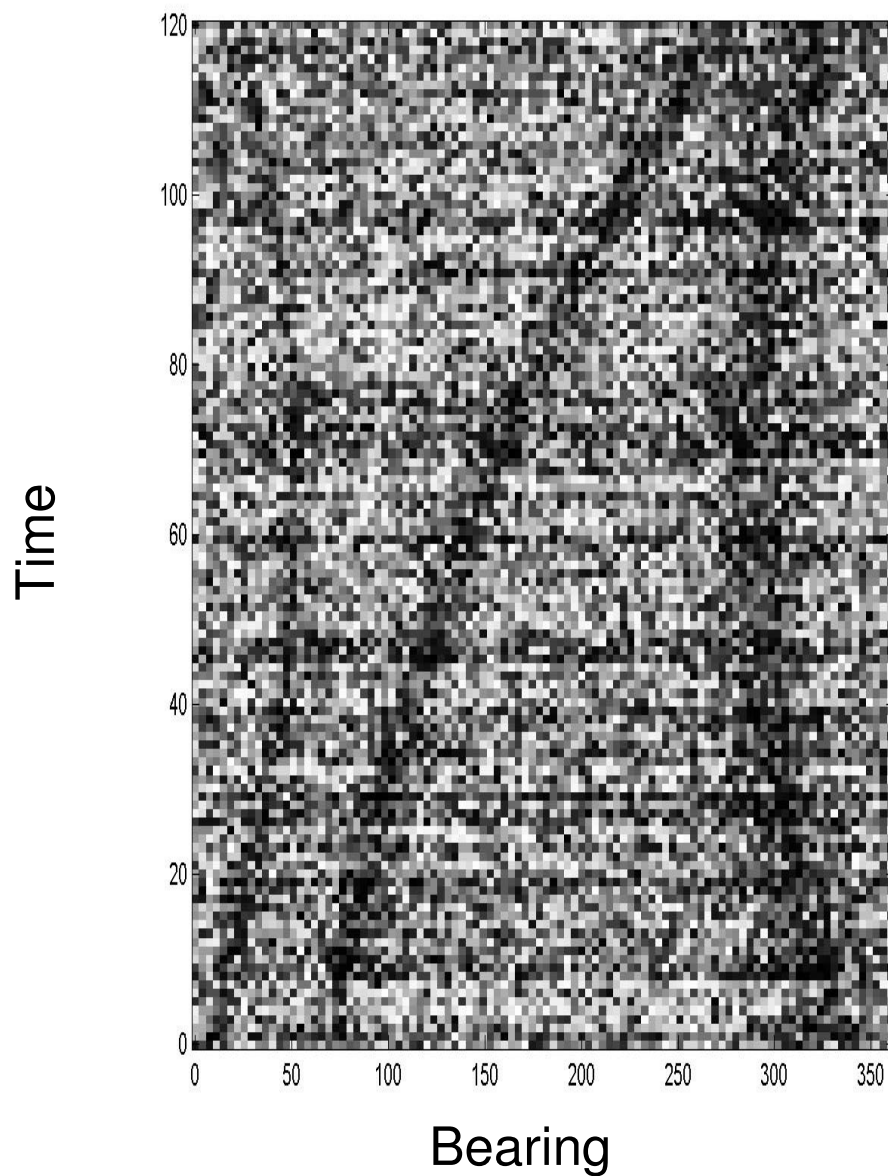
Narrow Targets, Increasing Intensity

Estimated ± 3 sigma overlaid on True Bearing



Intensity Data

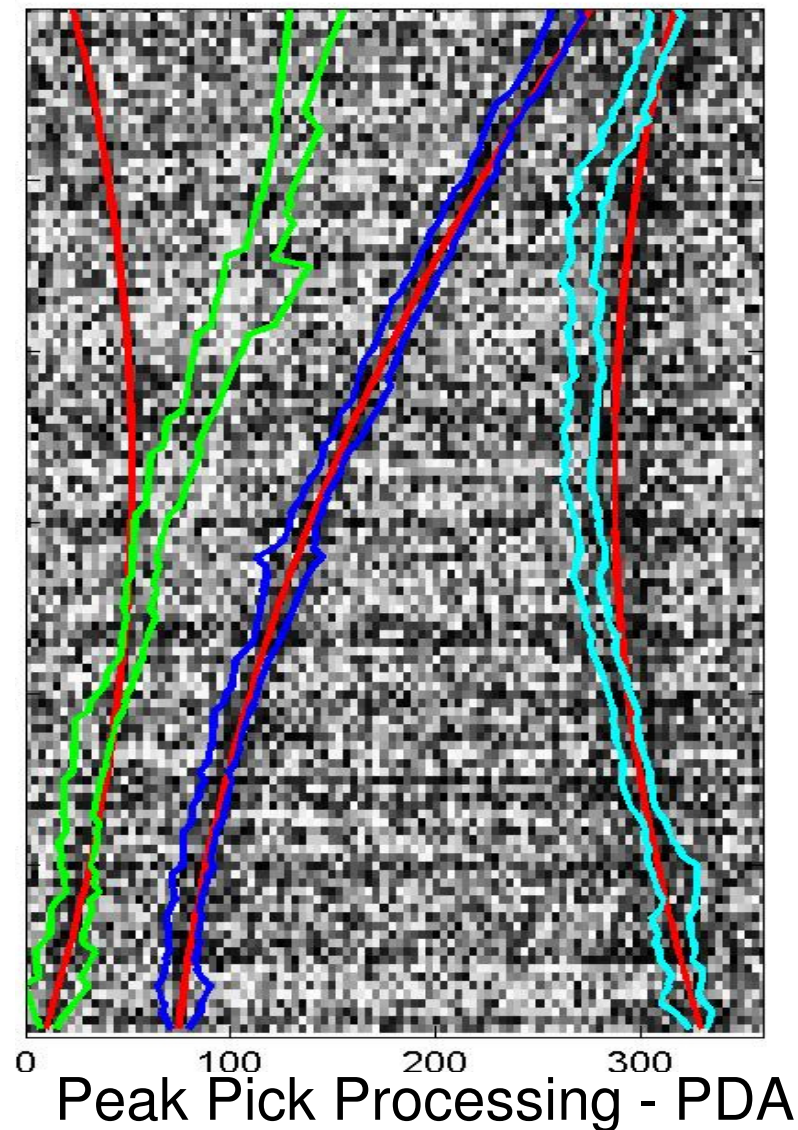
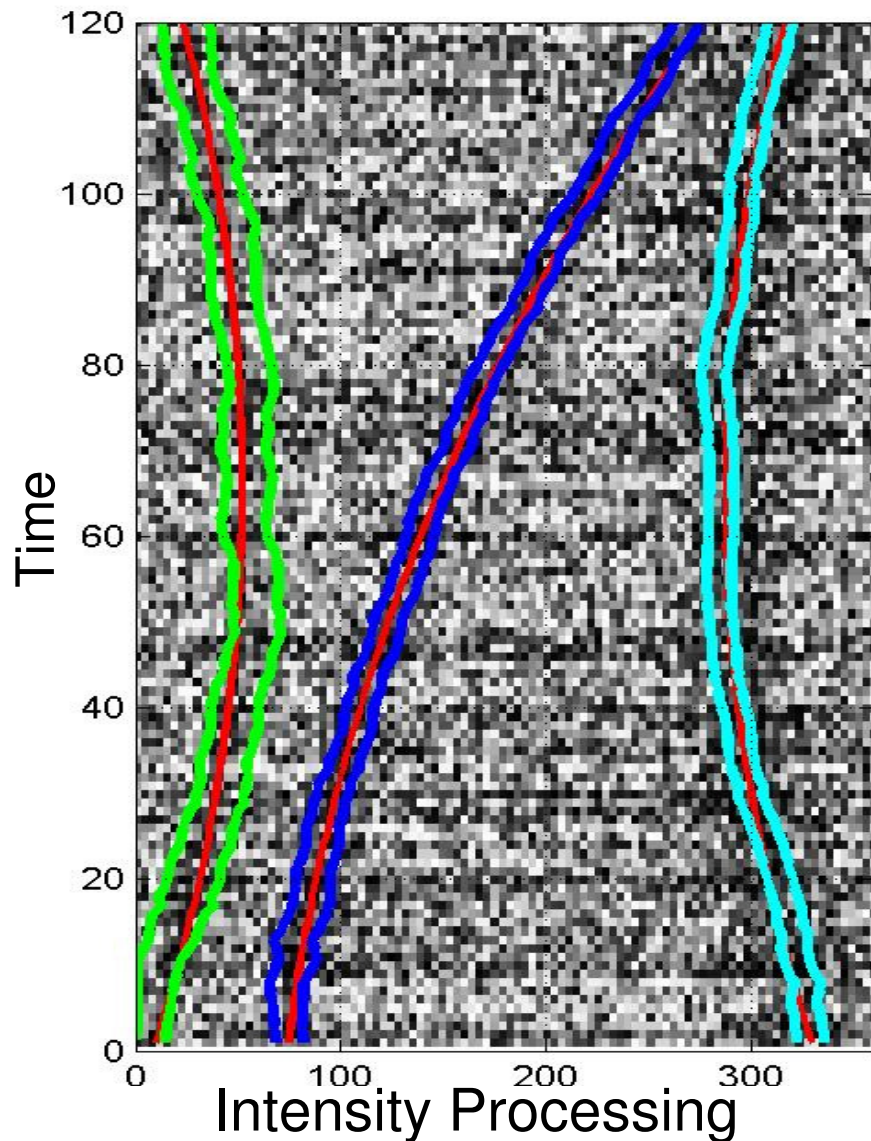
Fixed Amplitude, Varying width Targets



Single Target Tracking Results

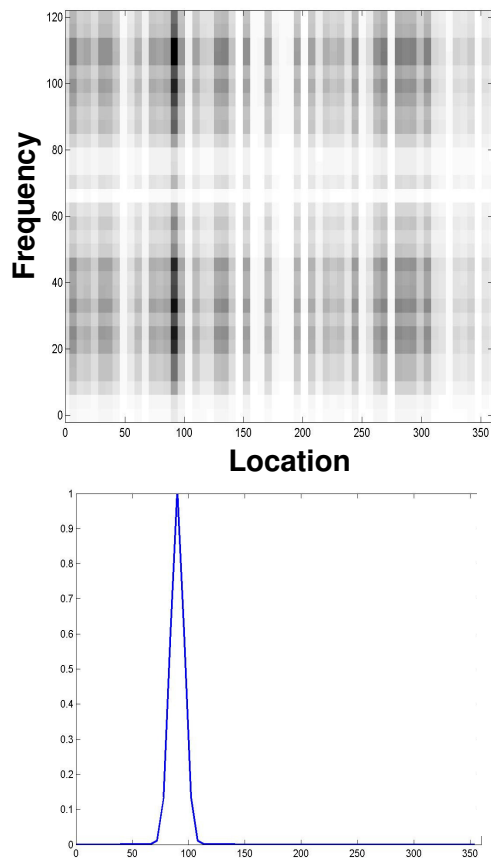
Fixed Amplitude, Varying width Targets

Estimated ± 3 sigma overlaid on True Bearing



Improving SNR & Separability

Data Scan



Non - parametric model of target spectral characteristics :

$$S_t^j = \{s_{t,1}, s_{t,2}, \dots, s_{t,k}\}^T$$

Outer product forms model of frequency - azimuth image :

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

Parametric model of spatial location :

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

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

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**