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Acoustic Source DOA Estimation using the Cross-Entropy Method (SYS 14)

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Acoustic Source DOA Estimation using the Cross Entropy Method

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Introduction: In this paper, we propose a novel implementation for the Maximum-Likelihood DOA estimator based on the Cross Entropy (CE) method. Simulation results show the proposed algorithm converges to the CRB within a few iterations, and the convergence speed is insensitive to the coherence of sources.

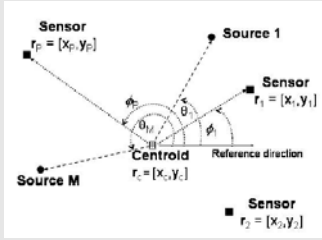
Features of AML DOA Estimator

- **Optimal in the ML sense**
 - Achieves CRB at high SNR.
- **Superior performance over many other suboptimal DOA estimators**
 - TDOA methods can only estimate single source DOA.
 - Subspace methods degrade severely when sources are strongly coherent.
- **High Complexity**
 - Multiple dimensional grid search is generally required.
 - Iterative maximization algorithms have been proposed in the literature.

Introduction of the CE Method

- **First proposed to solve the rare-event probability estimation problems**
- **Soon realized that it can be generalized to solve combinatorial and continuous optimization problems as well**
- **Translating the original deterministic optimization problems into stochastic optimization problems, which can be solved more efficiently.**
- **Global convergence has been observed in many problems.**

Introduction to ML Criterion for wideband DOA Estimation:



M wideband sources, P sensors

Data received by the pth sensor at time n:

$$x_p(n) = \sum_{m=1}^M S^{(m)}(n - t_{cp}^{(m)}) + w_p(n)$$

After N point DFT

$$X(w_k) = D(w_k)S(w_k) + \eta(w_k)$$

where $R(w_k) = X(w_k)X^H(w_k)$

$$P(w_k, \Theta) = D(w_k)D^H(w_k)$$

$$D^H(w_k) = (D^H(w_k)D(w_k))^{-1}D^H(w_k)$$

By techniques of separating variables, we can estimate DOA as:

$$\hat{\Theta} = \arg \max_{\Theta} J(\Theta) = \arg \max_{\Theta} \sum_{k=1}^L \text{tr}(P(w_{l(k)}, \Theta)R(w_{l(k)}))$$

In multiple sources case, AML requires multi-dimensional search.

Various numerical solutions (AP, GN, CG) have been proposed.

CE algorithm for wideband DOA estimation:

A summary of the proposed algorithm

1. Initialize parameters ρ , N_s , α , β , and $\hat{\mathbf{v}}(0)$. $\hat{\mathbf{v}}(0)$ can be chosen to incorporate the *a priori* knowledge of the DOAs.
2. Generate N_s samples $\Theta^{(1)}, \dots, \Theta^{(N_s)}$ from the proposal distribution $f(\cdot, \hat{\mathbf{v}}(t-1))$, where $f(\theta, \mathbf{v}) = \prod_{m=1}^M f_m(\theta_m, \mathbf{v}_m)$

$$f_m(\theta_m, \mathbf{v}_m) = \frac{1}{\sqrt{2\pi\sigma_m^2}} e^{-\frac{(\theta_m - \mu_m)^2}{2\sigma_m^2}}$$

3. Compute $J(\Theta^{(1)}, \dots, \Theta^{(N_s)})$. Set $\hat{\gamma}(t)$ as the order statistic $J_{[(1-\rho)N_s]}$.
4. Use the same samples $\Theta^{(1)}, \dots, \Theta^{(N_s)}$ to estimate the parameters $\tilde{\mathbf{v}}(t) = [\tilde{\mu}(t)^T, \tilde{\sigma}^2(t)^T]^T$ through the following update equations:

$$\tilde{\mu}_m(t) = \frac{\sum_{n=1}^{N_s} H(\Theta^{(n)}, \hat{\gamma}(t)) \exp(j\theta_m^{(n)})}{\sum_{n=1}^{N_s} H(\Theta^{(n)}, \hat{\gamma}(t))}$$

$$\tilde{\sigma}_m^2(t) = \frac{\pi^2}{3} \left\{ 1 - \frac{\sum_{n=1}^{N_s} H(\Theta^{(n)}, \hat{\gamma}(t)) \cos(\theta_m^{(n)} - \tilde{\mu}(t))}{\sum_{n=1}^{N_s} H(\Theta^{(n)}, \hat{\gamma}(t))} \right\}$$

5. Stop the algorithm when it converges; otherwise set $t=t+1$ and reiterate Step 2

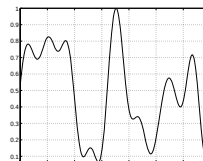
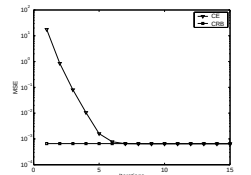
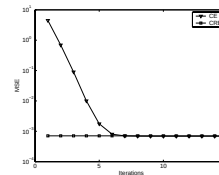
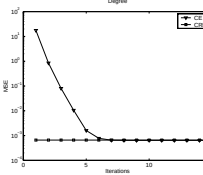
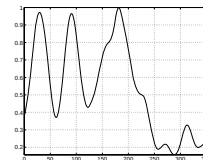
Simulation Results

Scenario 1: Incoherent Sources:

DOAs=30, 90, 180 degrees

8-element UCA with radius=0.25 m

Ns=200



Scenario 2: Coherent Sources:

DOAs=30, 90, 180 degrees

8-element UCA with radius=0.25 m

Ns=200

