Exploiting AML Algorithm for Multiple Acoustic Source 2D and 3D Estimations

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Introduction: Multiple acoustic source DOA estimation by fusing sensor array data

Sensor Array Beamforming

• Beamforming: space-time data collection and processing
  • Waveforms originating from multiple sensors are coherently combined in a time-synchronous manner.
  • Beamformed waveforms improve signal-to-noise ratio (SNR) compared with a single sensor system in the propagation medium that preserves sufficient coherency among received waveforms.
  • Beamforming can be used to determine the direction-of-arrivals (DOAs) and/or the locations of wideband/narrowband sources in the far/near field.
  • Low-cost acoustic sensor nodes based on advanced integrated circuit technology, signal processing and wireless communication capabilities facilitate beamforming-assisted source detection, separation and estimation.

Approximate Maximum Likelihood (AML)

• A likelihood-based algorithm that searches the event space for the most likely feature of the event.
  • ML estimator can be optimal under Gaussian noise model.
  • Subspace methods such as MUSIC or coherent signal subspace method (CSM) can be applied to wideband source signals but require either quasi-static property of signals or preprocessing that constructs focusing matrix or interpolation matrix.

Problem Description: DOA estimation requires space-time-frequency data exploration

Signal Model

\[ s_p(n) = \sum_{m=1}^{M} \left( r_{m}^{(p)}(n) (a - \hat{r}_{m}^{(p)}) + \eta_{m}(n) \right) \]

- \( M \) number of sources (assumed to be known and \( M < M \))
- \( r_{m}^{(p)} \) signal gain level of the \( m \)th source at the \( p \)th sensor (assumed to be constant within the block of data); source signal; fractional time-delay in samples (which is allowed to be any real-valued number); zero mean i.i.d. Gaussian noise with variance \( \sigma^2 \).

Space-Time Data Vectorization

- \( X(k) = D(k)S(k) + \eta(k) \)
- \( \max \mathcal{C}(\Theta) = \frac{N/2}{\min \sum_{k=1}^{N/2} \|X(k) - D(k)S(k)\|^2} \)
- \( \max J(\Theta) = \frac{1}{\min \sum_{k=1}^{N/2} \text{tr}(P(\omega_k, \Theta)R(\omega_k))} \)
- \( P(\omega_k, \Theta) = D(\omega_k)D(\omega_k)^T \)

Proposed Solution: One line with the main idea of the proposed solution

Alternative Projection Approach

• To break the multi-dimensional search into a sequence of single source parameter search.
  1st source: \( \phi_{s_1}^{(1)} = \arg \max_{\phi_{s_1}} J(\phi_{s_1}) \)
  2nd source: \( \phi_{s_2}^{(2)} = \arg \max_{\phi_{s_2}} J(\phi_{s_1}, \phi_{s_2}) \)
  Iterations: \( \phi_{s_1}^{(i)} = \arg \max_{\phi_{s_1}} J(\phi_{s_1}, \phi_{s_2}^{(i-1)}) \)
  \( \phi_{s_2}^{(i)} = \arg \max_{\phi_{s_2}} J(\phi_{s_1}^{(i)}, \phi_{s_2}^{(i)}) \)

Fisher Information Matrix & CRB

• To obtain the lower bound (CRB) on multiple source DOA (azimuth, elevation) estimation from inverse Fisher Information Matrix (FIM)

Sensor Array Geometric Configuration

• To reduce the impact of sensor array geometry on AML algorithm performance
  • An isotropic array yields mean-square DOA estimation errors independent of all azimuth and elevation angles.

AML-Based Multiple Source DOA Estimation

• Two sources in the far-field: acoustic data of a Mexican Antthrush and a male Dusky Antbird
  • Mexican Antthrush (left)& spectrum (right)
  • Dusky Antbird (left)& spectrum (right)

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