SOUND ANALYSIS, SYNTHESIS AND PROCESSING

DAAP Homework

Report on Source Localization Using Delay-and-Sum Beamforming

Objective

The goal of this assignment was to perform acoustic source localization using a uniform linear array (ULA) with 16 microphones. The localization method utilizes the delay-and-sum (DAS) beamforming approach, processing the recorded multichannel data in both time and frequency domains.

Implementation Overview

The code implements the following steps to achieve source localization:

1. **System Setup**:
   - The ULA consists of $M=16$ microphones spaced uniformly along a length of $L=0.45$ m.
   - The inter-microphone spacing d, is computed as $d=L/(M-1)$.
   - The speed of sound is taken as $c=343$ m/s, and the sampling frequency is $Fs=8000$ Hz
2. **Signal Processing**:
   - A custom Short-Time Fourier Transform (STFT) function was implemented to decompose the time-domain signals into time-frequency representations. The STFT is computed using:
     - Window length of 256.
     - Hop size of 128.
     - FFT size of 512.
   - Each frame of the signal is multiplied with a Hann window before applying the FFT.
3. **Beamforming**:
   - The DAS beamformer computes the pseudospectrum for each time frame and frequency bin using steering vectors designed for angles θ, ranging from -90° to 90°.
   - The steering vectors incorporate the array geometry and the wave properties.
4. **Pseudospectrum Visualization**:
   - The frequency-averaged pseudospectrum is computed and plotted as a 2D map with time on the y-axis and angles on the x-axis.
   - The resulting pseudospectrum is normalized and converted to a logarithmic scale for better visualization.
5. **DOA Estimation**:
   - The code identifies the Direction of Arrival (DOA) at each time frame by finding the angle corresponding to the maximum power in the pseudospectrum.

6. **Visualization**:
   - A static plot shows the ULA setup and the time-varying DOAs as arrows.
   - A video illustrates the DOA estimation dynamically over time, with arrows pointing to the estimated source positions.

Key Functions

- **STFT Implementation (`stft_custom`)**: A custom implementation avoids reliance on built-in MATLAB functions. It slices the signal into overlapping frames, applies a window function, and computes the FFT.
- **Steering Vector Calculation (`steering_vector`)**: This function models the propagation delay across microphones for plane waves arriving from various angles.
- **DAS Beamforming (`das_beamformer`)**: Computes the beamforming output by projecting the microphone signals onto the steering vector.

Results

1. **Frequency-Averaged Pseudospectrum**:
   - The generated pseudospectrum plot successfully shows the power distribution over time and DOA.
   - The logarithmic normalization highlights significant sources effectively.
2. **ULA Setup and DOAs**:
   - The ULA is visualized with microphone positions and DOAs depicted as arrows, indicating source directions dynamically over time.
3. **Localization Video**:
   - The video demonstrates time-varying source localization, showcasing the system's capability to track moving sources.

Challenges and Considerations

- **Wideband Sources**: The DAS beamformer is a narrowband technique. To handle wideband sources, the information was averaged across frequencies.
- **Resolution**: The array length and inter-element spacing limit the angular resolution. For better resolution, larger arrays or smaller microphone spacing are necessary.

Conclusion

The implemented solution adheres to the assignment requirements, providing a robust and modular framework for source localization using ULA. The code generates accurate visualizations and videos, demonstrating the effectiveness of DAS beamforming for real-time acoustic source tracking.
