Array Signal and Multichannel Processing

Lecture SS2025 – Programming Task

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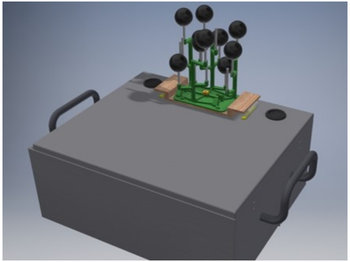
Outline

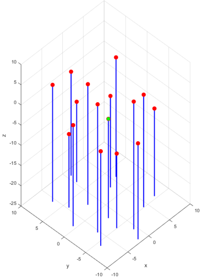
Programming Task

Description

Experimental System: Acoustic Crow's Nest Array

- Volumetric Microphone Array with 16 randomly distributed elements
- Condensator Microphones, frequency range: 5 Hz-100 kHz, sample frequency: 48 kHz
- Optimized for stationary or mobile operation on an unmanned ground vehicle
- Possible Applications: speech, shots, ground-based and airborne platforms

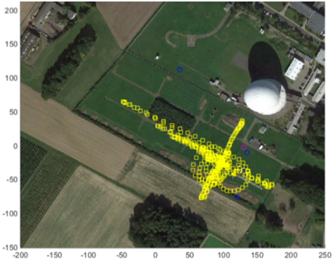




Programming Task
Description

Flight Experiment in Wachtberg

- Crow's Nest Array measuring the sound emitted by an Unmanned Ground Vehicle (UAV) in flight
- Challenge: Determine DOA of the sound emitted by the UAV



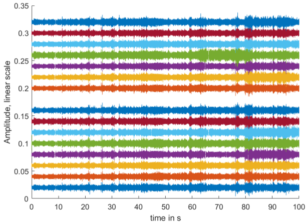
Given:
Consider the measurements from a flight experiment delivered from the described volumetric Crow's Nest Array with 16 elements. Channel 9 was not in operation during the experiment and is therefore missing from the measurement. In the folder "Measurements" you find the pre-processed measurements of the 15 channels. The measurements contain the recording of a drone flight over the microphone array of about 100 seconds duration. The data are band-pass filtered with cut-off frequencies from 2 kHz to 20 kHz. In addition to the pre-processed data, a file containing the raw data of the first channel is included in the data set.

Outline

Task 1: (*10 points*)

Consider the 15 preprocessed audio channels containing the UAV measurements.

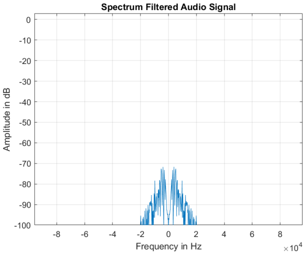
- Read in the prepocessed audio data from all 15 channels. If possible, use a built-in function in your programming environment, e.g. 'audioread' in MATLAB.
- Plot all 15 channels one above the other over a time-axis in one figure.

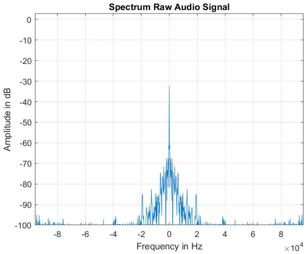


Programming Task
Task Description

Task 2: (*14 points*)
For the first audio channel, consider the pre-processed and raw data and perform the following steps for both signals:

- Transform the signal to the frequency domain via Fast Fourier Transformation with $N = 1024$. If possible, use a built-in function in your programming environment, e.g. 'fft' in MATLAB.
- Plot the spectra of the signals in dB over a frequency axis and compare both spectra.





Task 3: (*20 points*)
Examine the element geometry of the considered Crow's Nest Array. Attention: The elemet coordinates are given in centimeters! Assume a sound velocity of $c = 343\frac{m}{s}$.

- Compute the array factor $AF(u)$ for the highest considered frequency of 20 kHz.
- Plot the results in uv-coordinates with $u^2 + v^2 = 1$.
- Does the smallest element spacing fulfil the requirements for unambiguous DF results? If not, is this a problem?
- Calculate the maximum frequency from which the DF for the smallest element distance becomes unambiguous. Plot the array factor for this frequency.

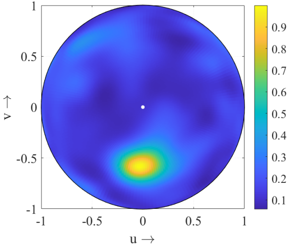
Task 4: (*20 points*)

Now use the pre-processed data again and consider the first second of the measurement data:

- Compute the spectrum of the signal via Fast Fourier Transformation with $N = 400$. For reasons of symmetry, use only the first half of 200 values for the following steps.
- Implement the incoherent broadband beamforming function based on the array transfer vector with $K = 200$ frequency bins:
  $$BF = \sum_{k=1}^{K} |\mathbf{a}^H(\mathbf{u}; \omega_k)\mathbf{Z}(\omega_k)|^2$$
- Calculate the function values of the beamforming function for a grid $(\alpha \in [0, 2\pi], \varepsilon \in [0, \pi])$ with a step size of 2°.

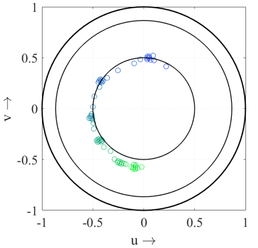
Task 5: (*12 points*)

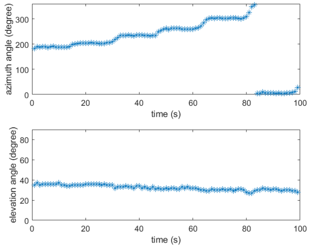
- Plot the beamforming function in uv-coordinates.
- Determine the maximum of the Beamforming Function and the corresponding azimuth and elevation angles in degrees: $\hat{\mathbf{u}} = \arg\max_{\mathbf{u}} \sum_{k=1}^{K} |\mathbf{a}^H(\mathbf{u};\omega_k)\mathbf{Z}(\omega_k)|^2$. An accuracy of 2° is sufficient.



Task 6: (*12 points*)
Now divide the audio data in 99 windows of 1 second length. For each window perform the steps described in Task 4 and 5 in order to estimate the DOA of the impinging signal.

- Plot the maximum of the beamforming function as a track in uv-coordinates for the complete measurement with one estimate per second
- Transform the uv-results into azimuth and elevation angles and plot both as a track over time.





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Task 7: (*12 points*)

- In two points in time the UAV signal is overlaid by speech and the DOA of the speech is determined. Think about how the UAV can still be located here.
- Think about how to reduce noise and amplify the UAV signal with array signal processing techniques.