Array Signal and Multichannel Processing

Lecture SS2020 – Programming Task

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Outline

Programming task

- Can be done individually or in groups (max. 3 students per group)
- 50% of points required for exam admission

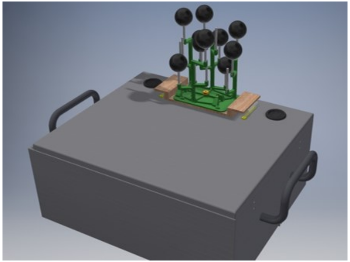
Submission

- Due date: Monday, 06.07.
- By email: marc.oispuu@fkie.fraunhofer.de
- Include name of group members and corresponding matriculation numbers in the email
- Attach code and plots to all tasks

Outline

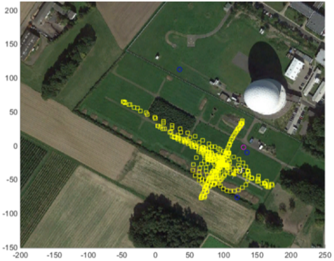
Experimental system: volumetric microphone array

- Array geometry: $M = 16$ randomly distributed elements
- Sensor elements: condenser microphones with frequency range: 5 Hz-100 kHz
- Element patterns can be assumed to be omnidirectional, i.e. can be neglected
- Signal acquisition: sampling frequency $f_\mathrm{s} = 192$ kHz
- Optimized for stationary or mobile operation on an unmanned ground vehicle
- Possible Applications: speech, shots, ground-based and airborne platforms



Experimental setup in Wachtberg

- Stationary microphone array measures the rotor noise emitted by a single ($Q = 1$) flying Unmanned Aerial Vehicle (UAV)
- Sensor task: Determine the direction of arrivals (DOA) of the UAV based on the rotor noise along the flight path of the UAV



Array geometry and recorded measurements

- Each recording has a length of 100 seconds
- Raw data of first microphone: UAV_1.wav
- Preprocessed data (band-pass filter with pass-band from 2 kHz to 18 kHz):

m	x_m/cm	y_m/cm	z_m/cm	Recording (c.f. Sciebo link)
1	-1.808	-2.390	-0.440	Preprocessed_UAV_1.wav
2	3.398	2.163	-2.385	Preprocessed_UAV_2.wav
3	-5.648	6.876	3.928	Preprocessed_UAV_3.wav
4	-1.789	-9.256	-1.255	Preprocessed_UAV_4.wav
5	5.752	3.134	4.559	Preprocessed_UAV_5.wav
6	-2.467	-4.962	-6.543	Preprocessed_UAV_6.wav
7	4.058	-4.927	2.834	Preprocessed_UAV_7.wav
8	-4.684	3.996	-6.812	Preprocessed_UAV_8.wav
9	-7.206	0.592	-0.005	Preprocessed_UAV_9.wav
10	-5.375	-3.333	6.708	Preprocessed_UAV_10.wav
11	0.729	8.731	0.717	Preprocessed_UAV_11.wav
12	-2.037	2.156	4.846	Preprocessed_UAV_12.wav
13	7.092	-4.499	-3.317	Preprocessed_UAV_13.wav
14	-7.178	-5.793	-1.598	Preprocessed_UAV_14.wav
15	-0.674	-7.188	6.603	Preprocessed_UAV_15.wav
16	0.333	7.047	-5.119	Preprocessed_UAV_16.wav

(The element locations are given in **centimeters**!)

Outline

1. Programming Task
   - Organizational Remarks
   - Description
   - Task Description

Total number of points: 100

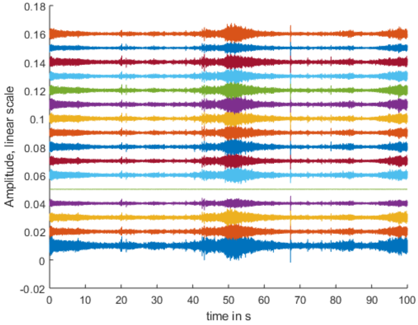
- Task 1: Read audio signals (*10 points*)
- Task 2: Frequency representation (*10 points*)
- Task 3: Array transfer vector (*15 points*)
- Task 4: Array factor (*15 points*)
- Task 5: Direction finding function (*15 points*)
- Task 6: Direction finding (*15 points*)
- Task 7: Direction finding II (*10 points*)
- Task 8: Array signal processing (*10 points*)

Programming Task

Task Description

Task 1: Read audio signals (*10 points*)
Consider the $M = 16$ preprocessed audio recordings.

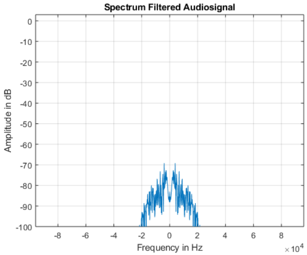
- Implement a function to read in the preprocessed audio recordings from all channels. If possible, use a built-in function in your programming environment, e.g. 'audioread.m' in MATLAB.
- Plot all channels.

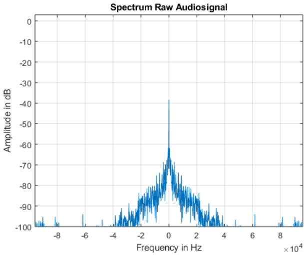


Task 2: Frequency representation (*10 points*)

For the first channel, consider the raw data and preprocessed data and perform the following steps for both signals:

- Transform the signal to the frequency domain using a DFT with $N = 1024$ frequency bins. Use a built-in function in your programming environment, e.g. 'fft.m' in MATLAB.
- Plot the spectra of both signals in dB over a frequency axis in order to visualize the effect of the band-pass filter.





Task 3: Array transfer vector (*15 points*)

Examine the array geometry of the considered volumetric array.

- Implement the array transfer vector for the considered volumetric array geometry $\mathbf{a}_0(\mathbf{u};\omega)$ with DOA $\mathbf{u} = (u, v, w)^T$. Assume a sound velocity of $c = 343$ m/s.
- Plot $\mathbf{a}_0(\mathbf{u};\omega)$ for each element. Consider the upper half-sphere in uv-coordinates with $u^2 + v^2 \leq 1$ and $w > 0$ and the frequency $\omega = 2\pi f$ with $f = 9$ kHz.

Task 4: Array factor (*15 points*)

Determine the spatial receiving characteristic for the considered array geometry based on the array transfer vector implemented in Task 3.

- Compute the array factor $AF(\mathbf{u};\omega) = \mathbf{a}_0^H(\mathbf{u}_0;\omega)\,\mathbf{a}_0(\mathbf{u};\omega)$.
- Plot $|AF(\mathbf{u};\omega)|$ for the upper half-sphere in uv-coordinates with $u^2 + v^2 \leq 1$ and $w > 0$. Consider the look direction $\mathbf{u}_0 = (0,0,1)^T$ and the frequency $f = 9$ kHz.

Task 5: Direction finding function (*15 points*)

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

- Compute the spectrum of the signal $Z_m(\omega)$ via Fast Fourier Transformation with $N = 400$ frequency bins, $m = 1, ..., 16$. 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:

$$BF(\mathbf{u}) = \sum_{k=1}^{K} \left|\mathbf{a}_0^H(\mathbf{u}; \omega_k)\, \mathbf{Z}(\omega_k)\right|^2$$

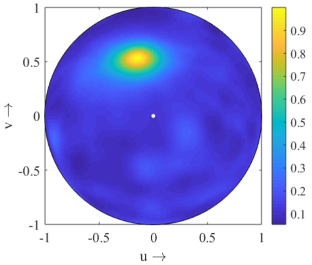
  with $\mathbf{Z}(\omega_k) = (Z_1(\omega_k), ..., Z_M(\omega_k))^T$
- Plot the aforementioned function in uv-coordinates for the upper half-sphere

Task 6: Direction finding (*15 points*)

- Assume a single source ($Q = 1$). Estimate the DOA by maximizing the direction finding function calculated in Task 5, i.e.

$$\hat{\mathbf{u}} = \arg\max_{\mathbf{u}} \sum_{k=1}^{K} BF(\mathbf{u}).$$

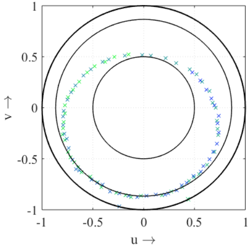
- Determine the corresponding azimuth and elevation angles in degrees.

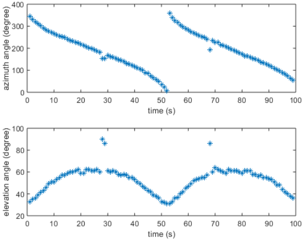


Task 7: Direction finding II (*10 points*)

Now consider the full pre-processed recordings and divide the audio data in 100 windows of 1 second length. For each window, perform the steps described in Task 5 and 6 and determine the DOA of the impinging signal.

- Plot the DOA estimates in uv-coordinates for the full recording with one DOA per second.
- Transform the uv-results into azimuth and elevation angles and plot the results over time.





Task 8: Array signal processing (*10 points*)

At two points, the UAV signal is overlaid by speech and the DOA of the speech is determined.

- Mention two array signal processing techniques to determine the DOA of the UAV.
- Outline the solutions (no implementation required).