Master's Department of Engineering Sciences

Name of the unit: Time-frequency analysis and spatialized sound

Lecturer: Sylvain ARGENTIERI (sylvain.argentieri@sorbonne-universite.fr)
Course code: UM4RBI23-Son
Student workload: 12h of lectures, 6h of tutorial sessions, 10h of lab sessions@
Credits: 3 ECTS

Specialization tracks:	- **E3A** :	☐ CIMES	☐ Syscom	☐ IPS
	- **AR** :	☐ ROBOT	☐ SI	☐ MeDH
	- **MECA** :	☐ MS2	☐ MF2A	☐ CompMech
		☐ ACOU	☐ EE	☐ EE APP

Semester offered: ☐ S1 ☒ S2 ☐ S3 ☐ S4
Language of instruction: ☐ French ☐ English
Targeted audience: ☐ Engineering Sciences students ☐ Other (specify):
Localization : ☒ PMC Campus ☐ Other (specify):

Course Overview

This course aims to train students in the analysis and processing, in terms of time and frequency, of a spatialized audio signal captured from antenna or binaural devices. The teaching then focuses on the analysis and synthesis of a 3D sound field.
Keywords: Signal processing, spatialized audio signal, time-frequency analysis, acoustic propagation; source localization: beamforming, high-resolution methods, binaural perception; spherical harmonics, Wave Field Synthesis (WFS), Ambisonics.

Prerequisites

Students should have previously acquired the following prerequisites to follow this course:

- Analog signal processing: convolution, series, and continuous-time Fourier transform;
- Discrete signal processing: Discrete Fourier Transform, Discrete Fourier Transform, correlation;
- Basic concepts in linear algebra.

Intended Learning Outcomes

By the end of this course, students will be able to:

1. Understanding and modeling the propagation of a source in an ideal environment.
2. Identify the characteristics of a spatialized audio signal in the time and frequency domains.
3. Modeling acoustic information measurement from a device consisting of one or more microphones.
4. Analyzing multichannel signals to estimate the position of one or more sound sources in space.
5. Modeling the acoustic effect of a head on a binaural recording system.
6. Knowing how to decompose an acoustic field into spherical harmonics.
7. Analyze and synthesize a sound field.
8. Implement a multi-channel capture system.
9. Program algorithms for locating, analyzing, and synthesizing a sound field

Indicative Teaching Sequence and Methods

Week	C/TD/TP*	Content	Preparation	Learn. outc.
S1	C1	Fundamentals of acoustics: propagation with or without a source		AAV1-2
S2	C2	Sound source localization: modeling and application to beamforming		AAV2-3
S3	TD1	Acoustics: Green's functions, plane/spherical waves		AAV1
S4	C3	Sound source localization: high-resolution methods (MUSIC, DUET/ESPRIT)		AAV3-4
S5	TP1 (4h)	Characterization of acoustic propagation		AAV1-2
S6	C4	Localization of sound sources: binaural perception (HRTF, spatialization)		AAV3-5
S7	TD2	Sound source localization: TDOA estimation using generalized correlation		AAV3-4
S8	C5	Spherical harmonic decomposition		AAV6
S9	TP2 (3h)	Experimental implementation of a localization method		AAV8-9
S10	C6	Sound field analysis and synthesis (WFS, Ambisonics, modal beamforming)		AAV7
S11	TD3	Multiple-choice questions + Time/frequency/space analysis		AAV7
S12	TP3 (3h)	Measurement and analysis of spatialized impulse responses		AAV8-9

* C/TD/TP respectively corresponds to lectures, tutorials and lab sessions.

Sequence of the unit:
The unitis divided into three sequences:
- Sequence 1: Fundamentals of acoustics = C1+TD1+TP1
- Sequence 2: Spatialized sound; application to source localization (C3/4/5 + TD2 + TP2)
- Sequence 3: Spatialized sounds, time-frequency-space analysis-synthesis (C5/6 + TD3 + TP3)

Indicative Assessment of Intended Learning Outcomes (1st session)

Week	Individ./group	In-person/remote	Type of exam	Evaluated outcomes	Scale %
S11	Individual	In-person	Quiz	AAV 1 à 5	15 %
S13	Individual	In-person	Written	AAV 1 à 7	50 %
S13	Individual	In-person	Labs	AAV 8-9	35 %

2nde session of exam

Session	Individ./group	In-person/remote	Type of exam	Evaluated outcomes	Scale %
2	Individual	In-person	Written		65 %
1	Individual	In-person	Labs	AAV 8-9	35 %

Bibliographic references

- Bruneau, M. (2013). Fundamentals of acoustics. John Wiley Sons.
- Hartmann, 1996, "signal, sound and sensation", Springer-Verlag
- Imai Abe, "Spectral Envelope Extraction by Improved Cepstral Method"
- Van Trees, Harry L. (2002). Optimum Array Processing: Part IV of Detection, Estimation, and Modulation Theory. Wiley.
- Rafaely, B. (2019), Fundamentals of Spherical Array Processing. Springer

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