Room boundary estimation

Master thesis

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Agenda

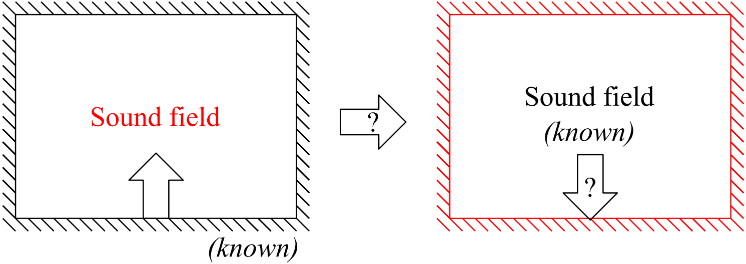
Introduction

Problem analysis

System design

Conclusion and further research

Introduction
Presentation of problem



There exists a unique relationship from the **boundaries** to the **sound field** *(Kirchhoff-Helmholtz theorem)*.

Problem statement: *how can boundaries' characteristics be evaluated based on acoustical measurements in the room?*

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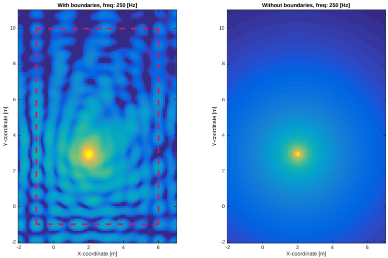
This problem is not new, some approaches exist:

- Acoustical:
  - From measured echoes *[Jager, 2015]*
  - Using a directional microphone *[Gunel, 2016]*
- Optical:
  - Using a Kinect camera *[Olesen et al., 2014]*

The acoustical ones are limited to **simple geometries** or a **low degree of precision**, while the optical is almost useless for the estimation of materials' characteristics.

Effects of having boundaries *(finite enclosures)*

- Sound pressure is not radially decaying
- Maxima and minima found depending on freq. and boundaries



Identifying the components of the sound field within the enclosure:

- **Direct sound** (single wavefront)
- **Reflected sound** (multiple wavefronts)

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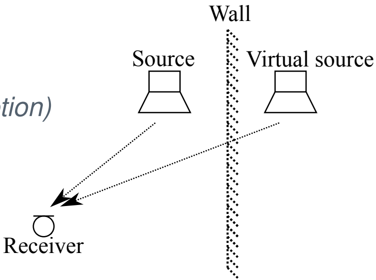
Reflections understood as **virtual sources**

- Delayed *(longer path)*
- Filtered *(reflection absorption)*



Any enclosure can be modeled after a set of virtual sources that represent the effect of the reflections.

New task: *find the set of virtual sources.*

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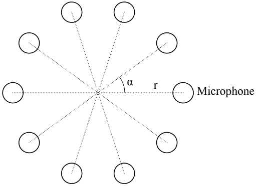
All information is obtained from **IR measurements** performed with an **array**.

Uniform circular arrays offer:

- Homogeneous resolution
- Good performance over freq.

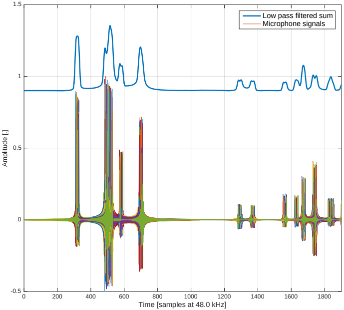


Better geometries can be derived from the UCA.

Using IRs allows the data to be processed using **narrow or wide band techniques** (e.g. it can be filtered).

Data captured with the array is a **set of impulse responses**.

- One IR per microphone
- Signals are analysed **group or individually**



There exist **zones of interest** where the analysis must focus.

$\Rightarrow$ These *events* lead to **estimated sources**.

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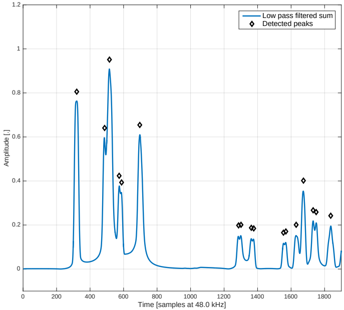
Combining and low-pass filtering the IRs, the zones of interest are found.

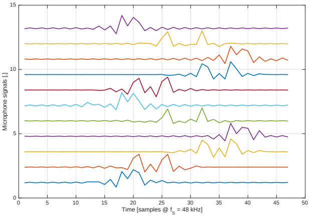
- The analysis of IRs is only performed on those zones greatly **reducing the computation time.**
- It almost eliminates the **false detections** that other methods show.



System design
IR processing II - Time windowing

Each zone of interest is processed for:

- **Detection** (amount of events)
- **Direction of arrival** estimation
- **Spectrum** estimation



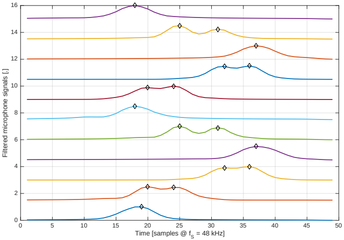
Sources are defined with characteristics derived from these estimations. This process creates a **cloud of virtual sources** with location and spectrum.

Classic detection methods are not valid or impractical:

- **Eigenvalue decomposition**: not valid for coherent signals
- **GLRT** (hypothesis testing): threshold value is hard to find and change with the environment

A new method is designed for this specific needs:

- Each microphone signal is **rectified and filtered**
- A **peaks-detection** method is executed
- The **mode** of the amount of peaks is taken



DOA estimation and what choices were made:

- Widely used, precise methods:
  - MUSIC
  - ESPRIT
  - Capon

These methods will fail with **coherent** signals present. Another method was chosen:

- Stochastic maximum likelihood estimator (**SML**)

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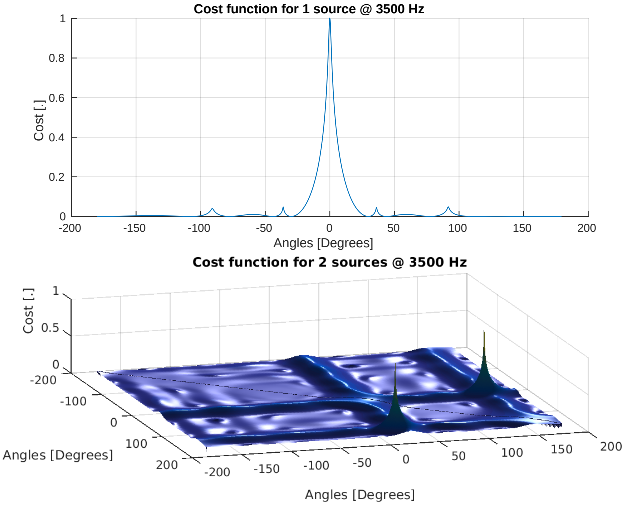
System design
IR processing IV - DOA estimation

The **SML** works with **coherent** signals:



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Minimizing the **SML** estimator. Several possible minimizing techniques exits such as:

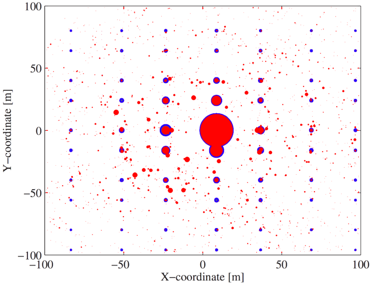
- Newtons method
- Hillclimbing techniques
- Genetic algorithms

A **genetic algorithm approach** was chosen. Reasons are:

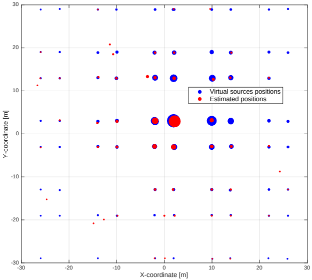
- Good solutions space search
- Fast convergence
- Consistent convergence

System design
Virtual sources cloud

A **virtual sources cloud** is estimated from data of IRs analysis



(Existing method)



(New developed method)

- **False detection** is almost eliminated.
- **Computational time** is greatly improved.

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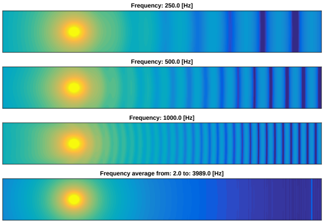
System design
Sound field reconstruction I

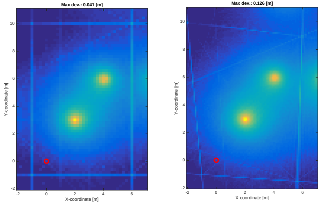
New geometry estimation principle:

- From the **cloud of sources**
- Use **Green's function** to re-construct the pressure map
- **Average over frequency** to get the boundary silhouette *(prime numbers)*

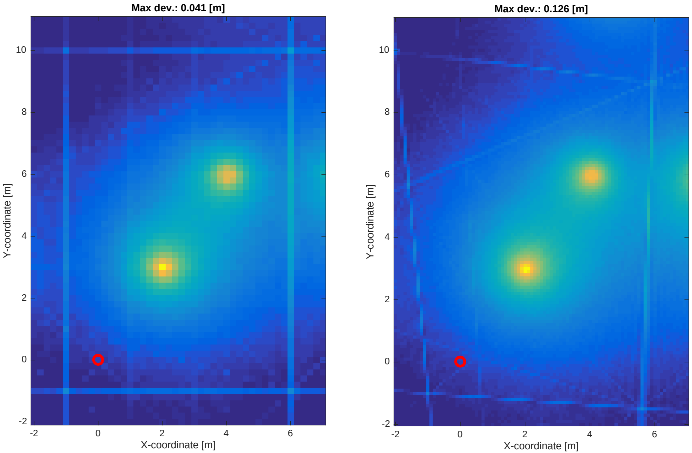


This procedure is applied for full clouds of virtual sources:

- It is shown to work for any **arbitrary geometry**
- **Spacial averaging** concept is introduced



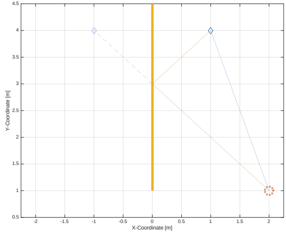
Rectangular and **irregular** boundaries examples:



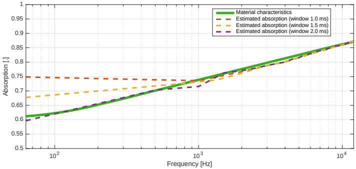
System design
Sound field reconstruction II

Deriving **boundaries' absorption** from virtual sources:

- From the **estimated geometry**
- Analysing the spectrum of **direct** and **reflected rays** *(in the IRs)*
- **Beamforming** is necessary if several events coincide in the same time window



- The estimated absorption characteristics are valid in the **mid - high freq** range *(window size)*



Conclusion and further research
Results

Proven facts and developed **new methods**:

- New methods for **IRs analysis** and **VS estimation**
  - **Zones of interest** detection
  - **Amount of events** estimation *(peak detection)*
- **SML-DOA** efficiency estimation for cloud decomposition
  - Evaluation of standard (scan) and intelligent minimiser (GA)
- **Principle of *freq superposition*** for geometry estimation
  - Shown to work for **arbitrary geometries**
  - **Spatial averaging** proven to work
- Method for **boundaries absorption** estimation
  - Proven to work although limited to mid-high frequency

Conclusion: *all elements needed for a real-time system implementation are ready*

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The **basic elements** are working, but there is room for improvement:

- Improve **geometry estimation** precision (small details, presence of furniture, etc).
- Expand **absorption estimation** frequency range.
- Extend the system to a **3D** version
- Evaluate the complete setup with **real IRs** in 3D
- Implement a **real-time** system

Room boundary estimation
Master thesis presentation - June 2016