TECHNISCHE UNIVERSITÄT CHEMNITZ

Fakultät für Informatik

Juniorprofessur Media Computing

Juniorprofessur MEDIA COMPUTING

localizeit

Bundesministerium für Bildung und Forschung

INTENTA ADVANCED RECOGNITION COMPONENTS

3D MICROMAC

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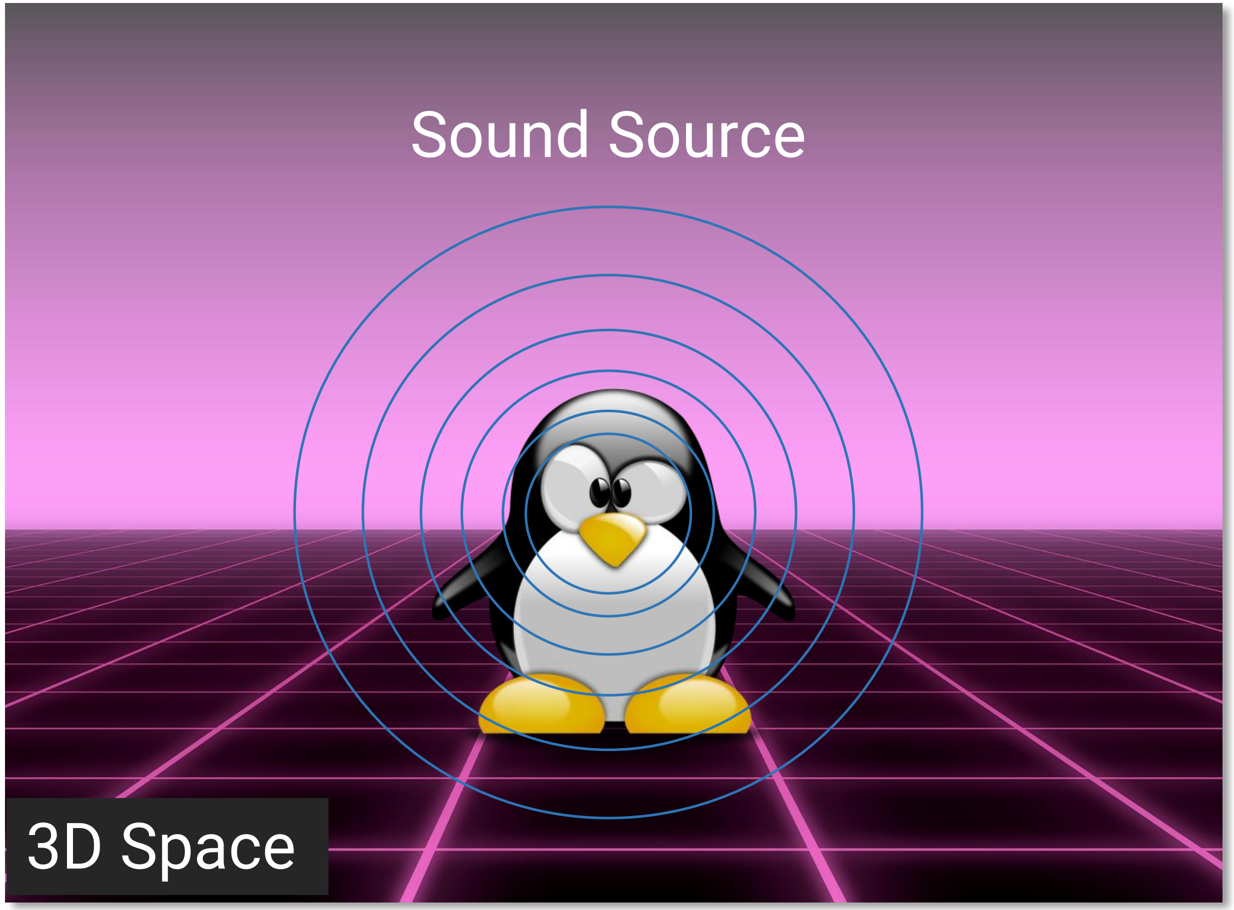
3D Indoor Audio Localization of Moving Objects

What is 3D Acoustic Source Localization?



Determination of the Position of a Sound Source in 3D Space

So we are trying to answer the question:
Where is Tux?

$$P_{\mathrm{Tux}} = (x, y, z)\ ?$$

How is 3D Acoustic Source Localization typically approached?

1) Multiple microphones at ***known***, fixed locations
2) Record sound emitted by sound source
3) Deduce sound source position

Loalization Method Categories

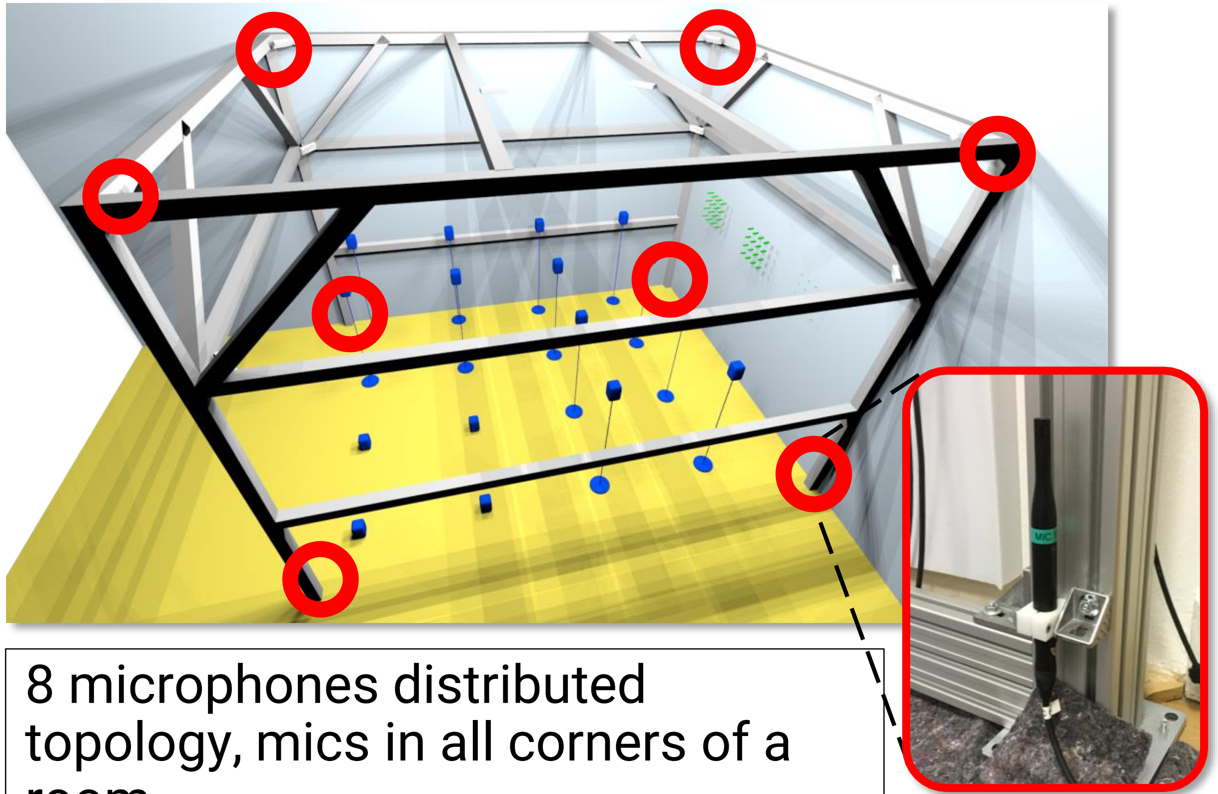
- Time Difference of Arrival (TDOA)
- Beamforming
- Equation System-based

Microphone Geometries

- Planar arrays
- Distributed topologies

Microphone Geometries – Planar Arrays vs. Distributed Topolgies

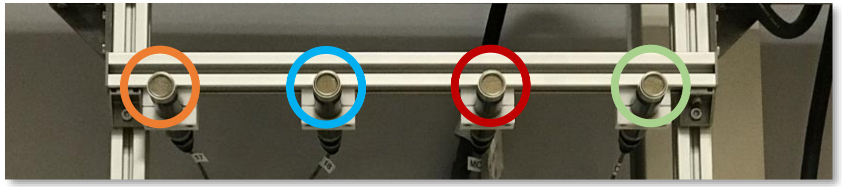
16 microphones planar array, 4×4 rectangular configuration



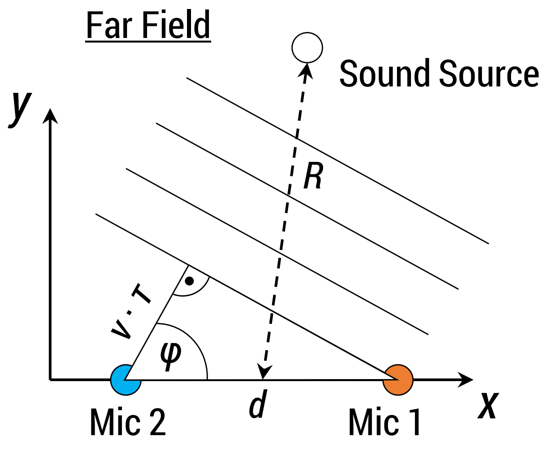
8 microphones distributed topology, mics in all corners of a room

How does TDOA based Localization work with Planar Arrays?

Step 1 [1]
Calculate Angle of Arrivals (AOAs)

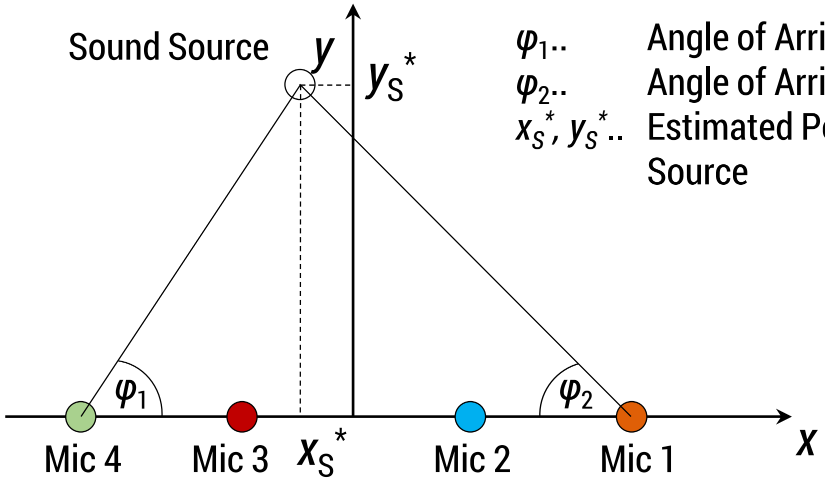

Upper Row of 4x4 Microphone Array

[2] **Step 2**
Combine AOAs and localize Sound Source



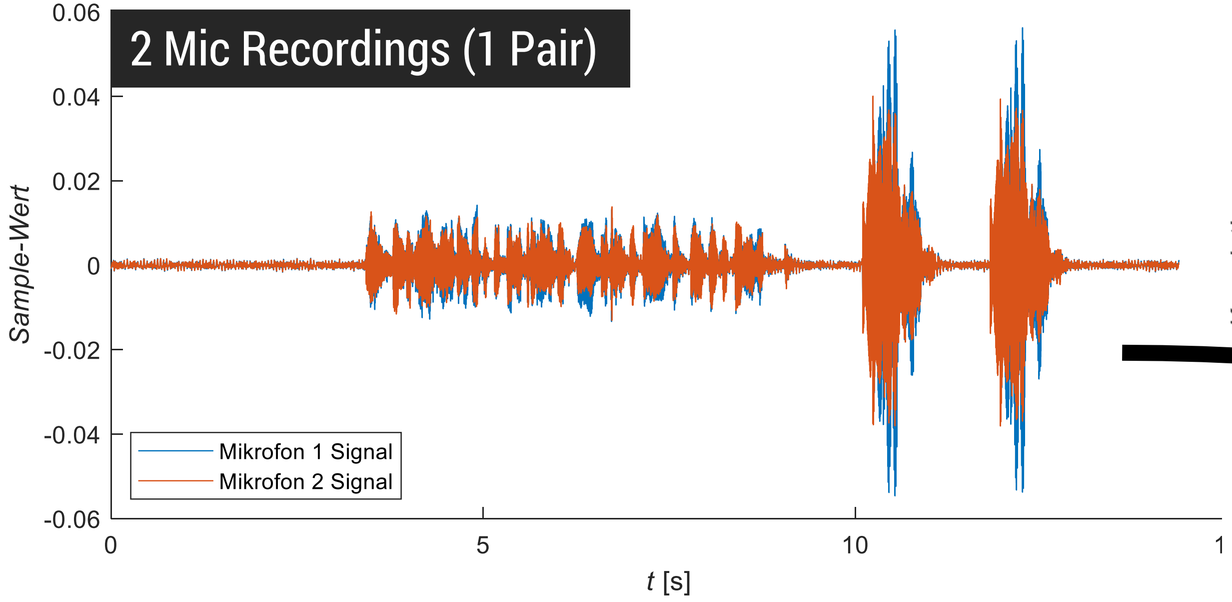
φ.. Angle of Arrival
d.. Distance b/w Microphones
R.. Average Distance b/w Sound Source & Microphones
v.. Speed of Sound
λ.. Wave Length
τ.. Measured Time Delay b/w Microphone Signals

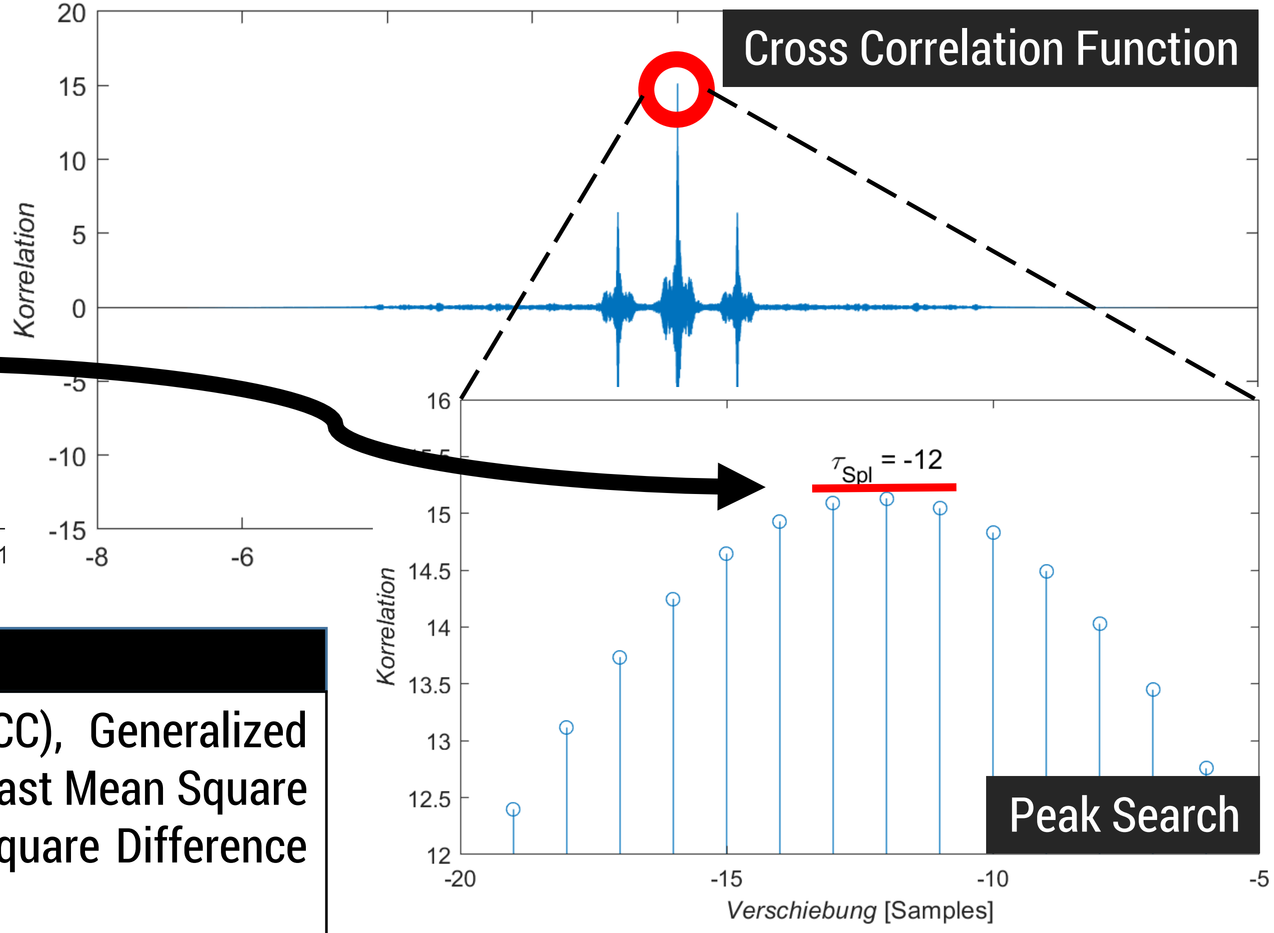
$$\varphi = \cos^{-1}\left(\frac{v \cdot \tau}{d}\right), \text{ for } R > \lambda$$



φ_1.. Angle of Arrival Mic Pair 1
φ_2.. Angle of Arrival Mic Pair 2
x_S^*, y_S^*.. Estimated Position of Sound Source

Estimating τ – Time Delay Estimation



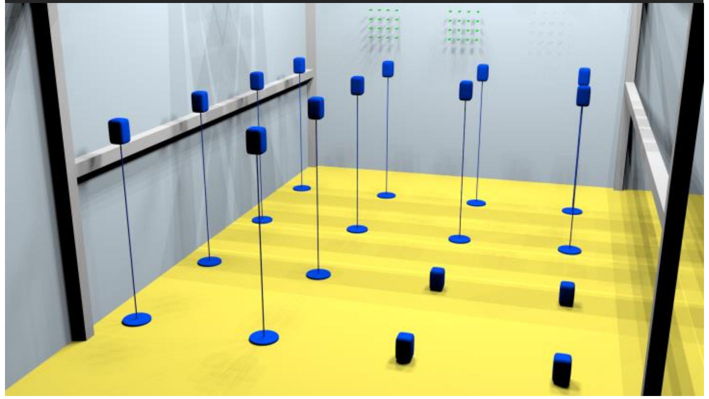


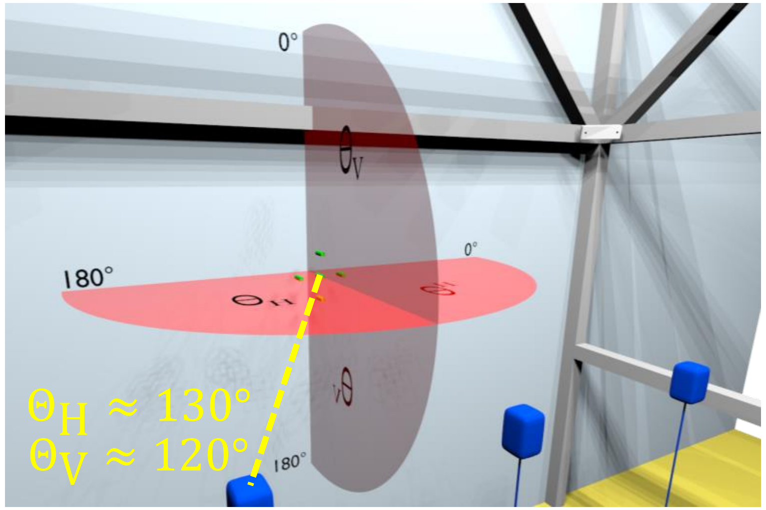
Selection of Time Delay Estimation Methods [3]

Cross Correlation (CC), Generalized Cross Correclation (GCC), Generalized Cross Correclation Phase Transform (GCC-PHAT), Adaptive Least Mean Square Filter (LMS), Maximum Likelihood Estimator (ML), Average Square Difference Function (ASDF)

MC Localization Dataset I – Static Sources & Planar Arrays

MC Localization-Dataset I	
Place	Media Computing Lab
Author	Dr. Hussein
Sound Sources	16 loudspeakers coordinates known
Source Audio	10s newscast
Microphones	56 microphones in 3 arrays coordinates known
Methodology	16 loudspeakers consecutively played back the cource audio file. One recording per loudspeaker

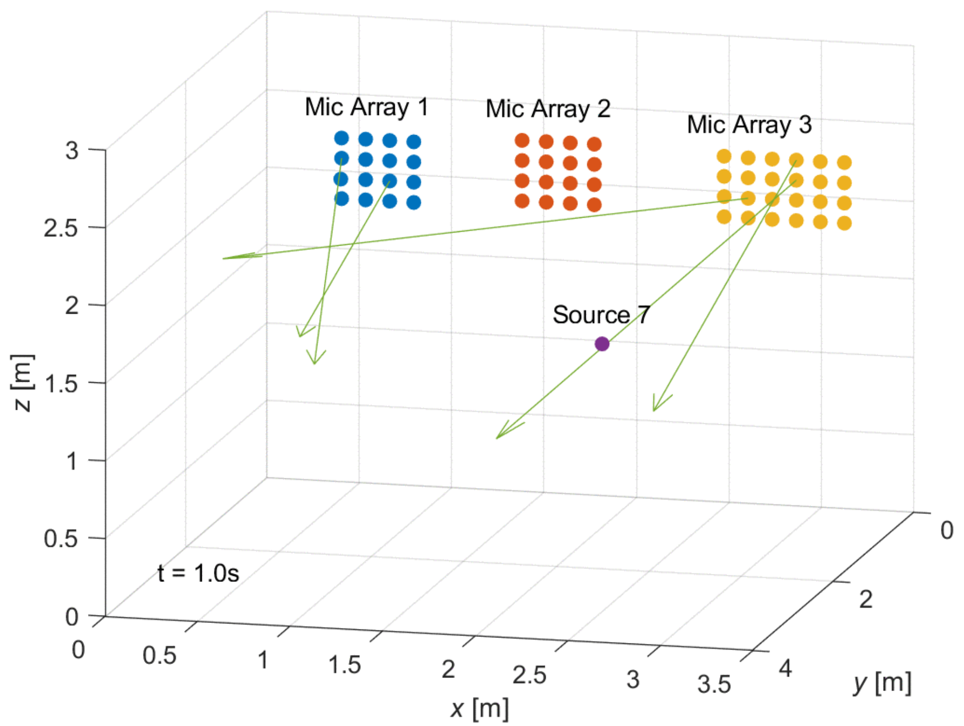

Real & Virtual Scheme of Dataset


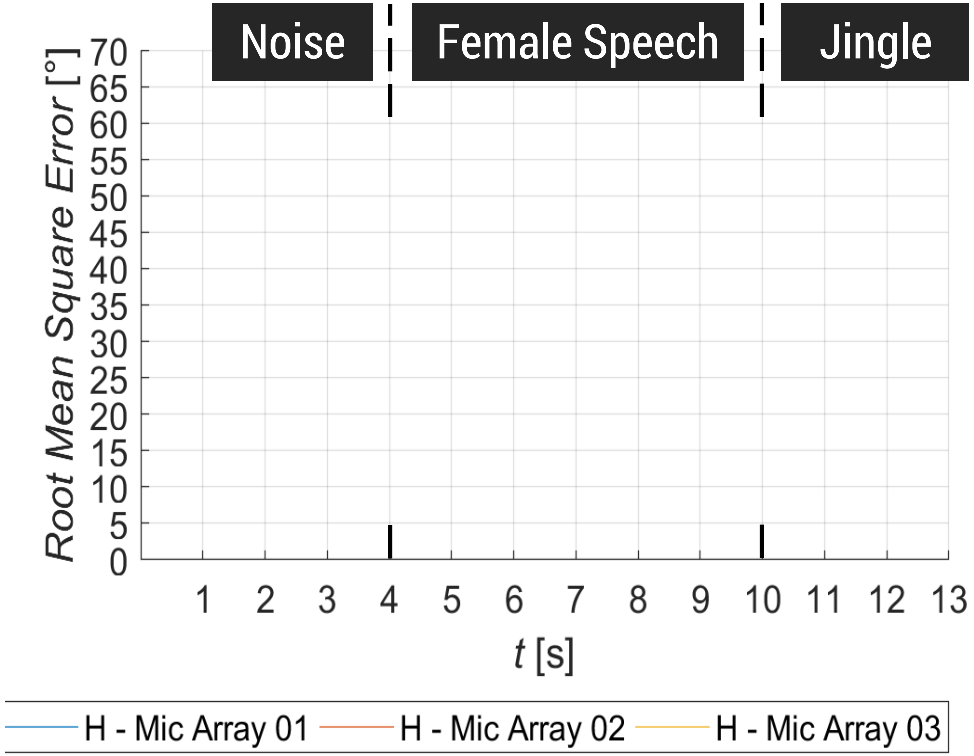


Angle Conventions & 3D AOA Example

MC Localization Dataset I – Results & Visualization (TDOA Method)

Step 1
Calculate Angle of Arrivals (AOAs)

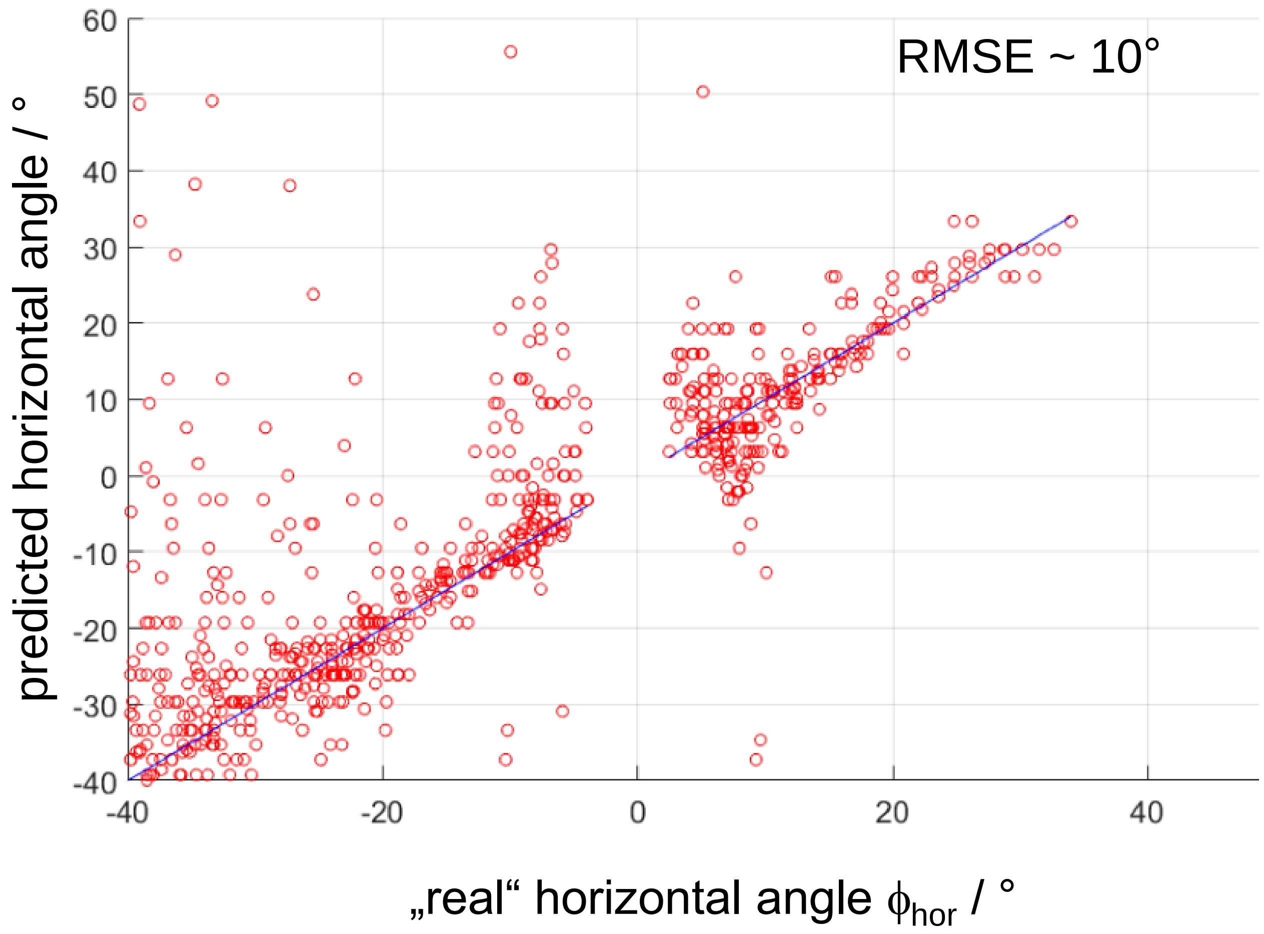




Step 2 Combine AOAs and localize Sound Source

Calculate 3D region (e.g. sphere) in which the AOA vectors are spatially particularly close

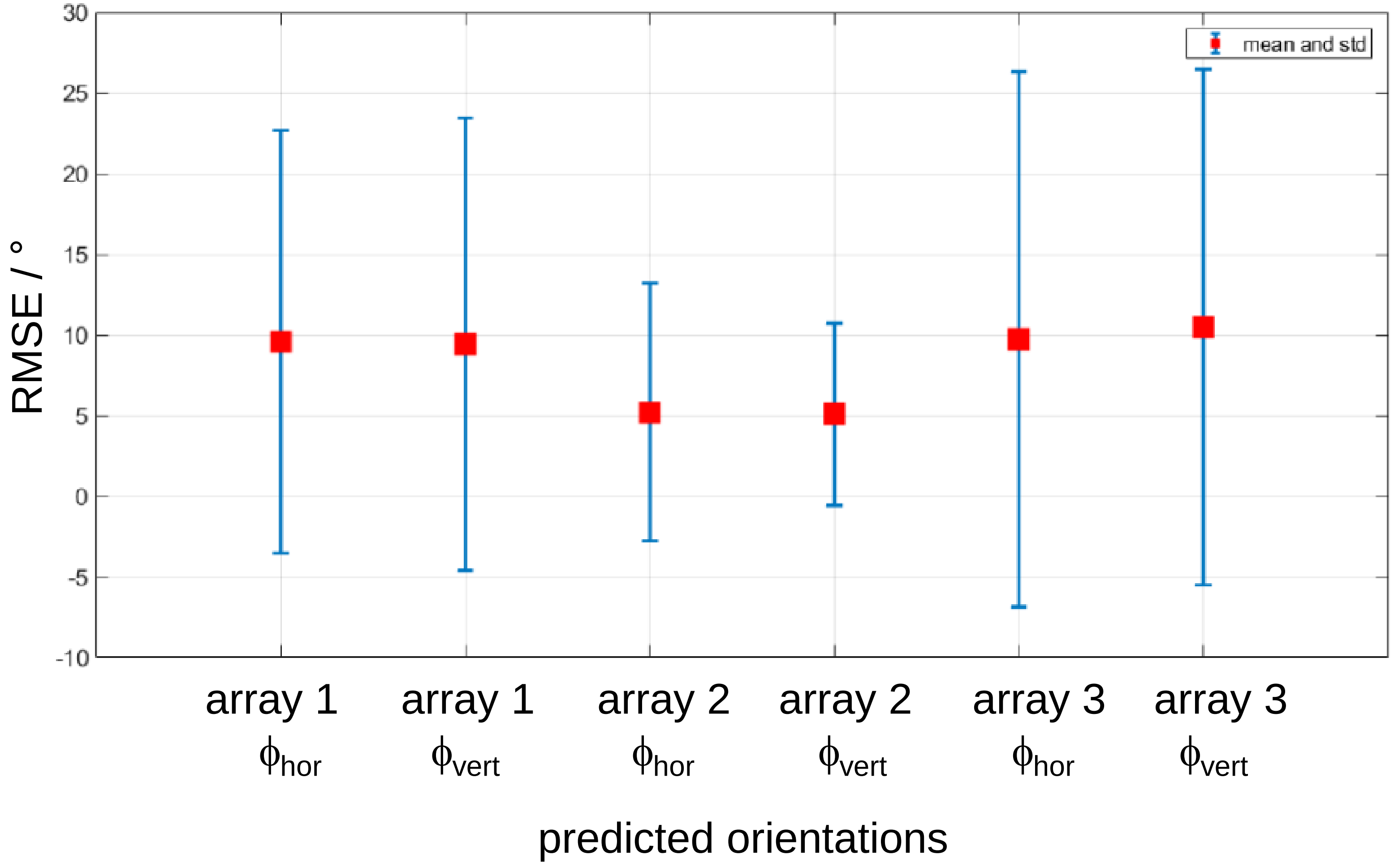
MC Localization Dataset I – Location Determination Results of static sources



- 60 different horizontal microphone pair combinations
- 16 sound sources
- microphone array 3 (24 microphones)

→ RMSE - Root Mean Squared Error to estimate deviations from model

MC Localization Dataset I – Location Determination Results of Static Sources



Average over 16 static sources

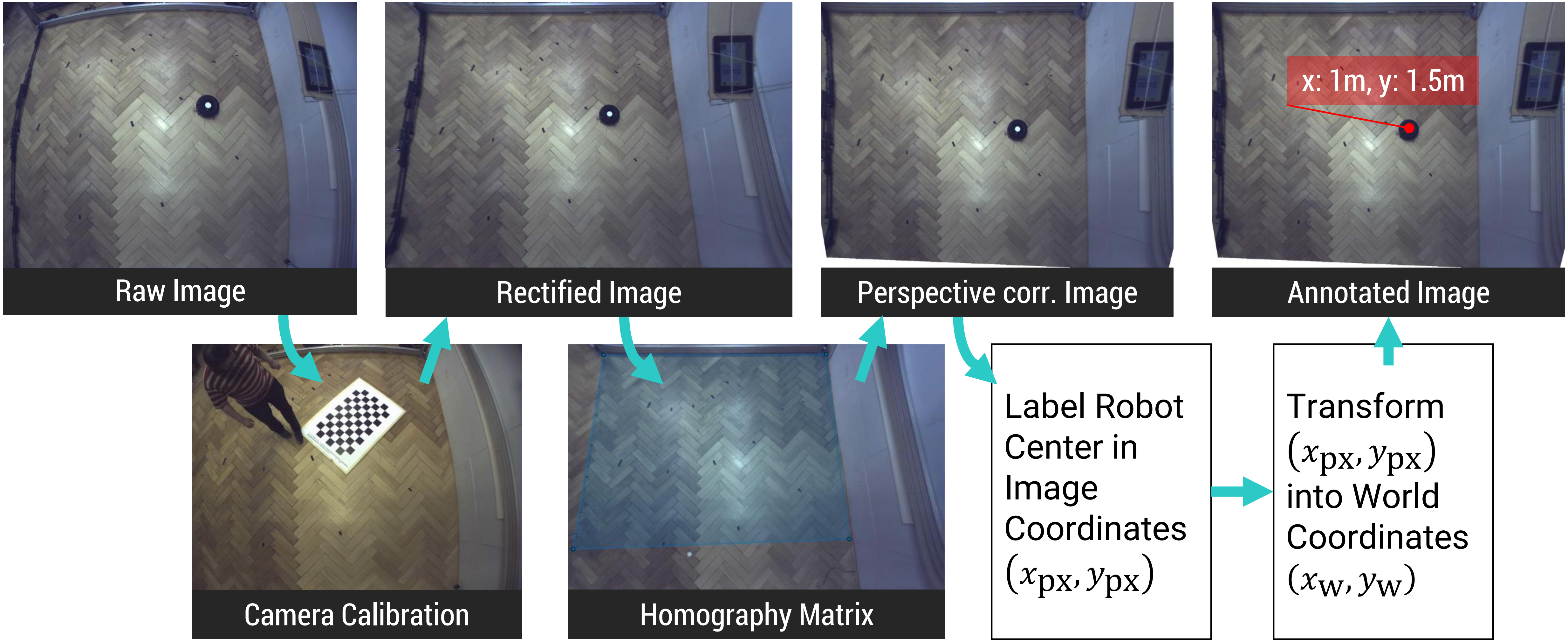
→ Most accurate: Array 2: cardioid pattern

MC Localization Dataset II – Dynamic Sources

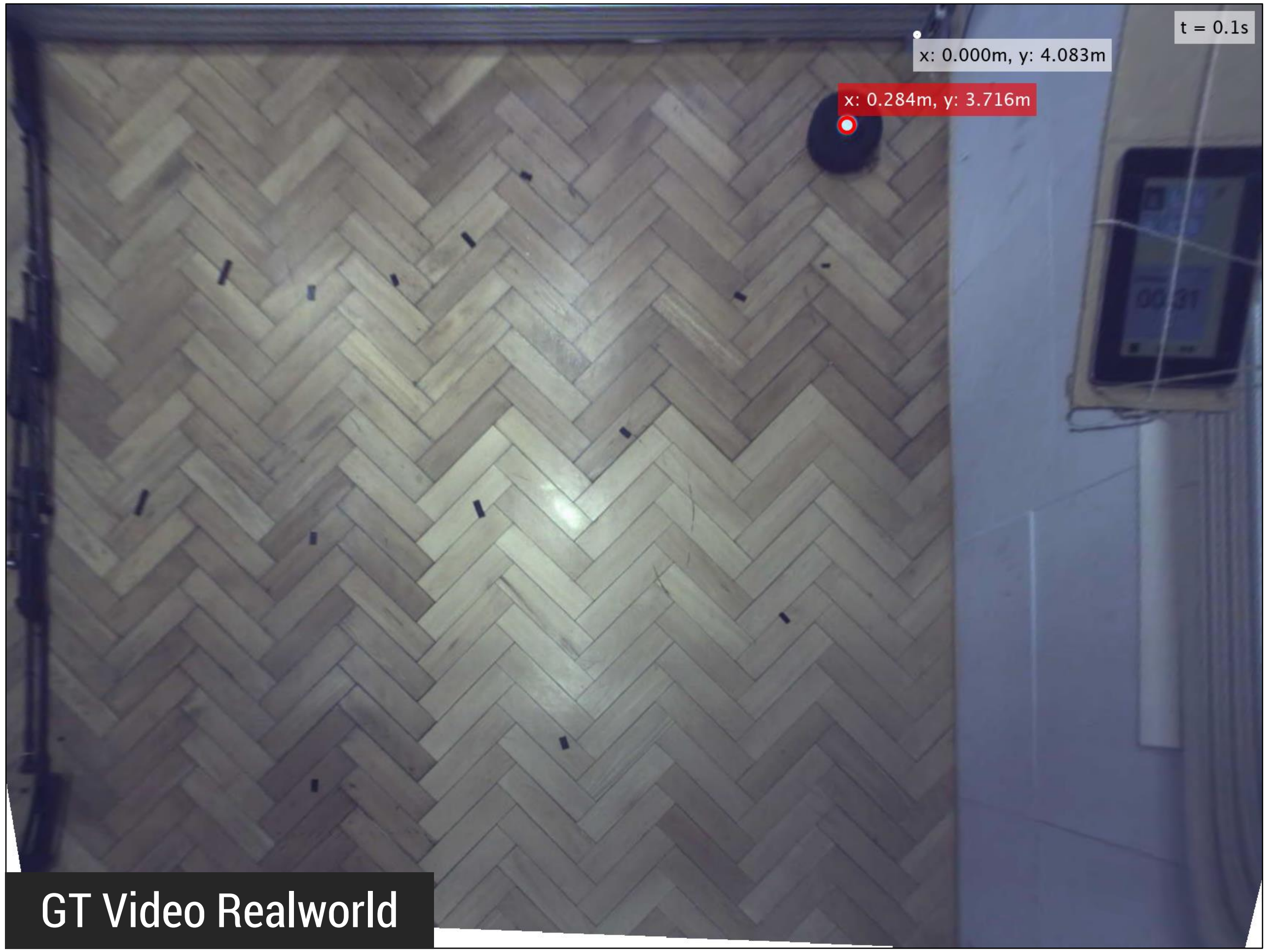
MC Localization-Dataset II	
Place	Media Computing Lab
Author	R. Erler & F. Schmidsberger
Sound Source	Moving vacuum cleaner robot, ***coordinates known***
Source Audio	Noise
Microphones	48 mics in 3 arrays, 8 mics in corners, coordinates known
Methodology	Record audio and topview video synchronously while robot vaccums the floor

Example Video from Dataset

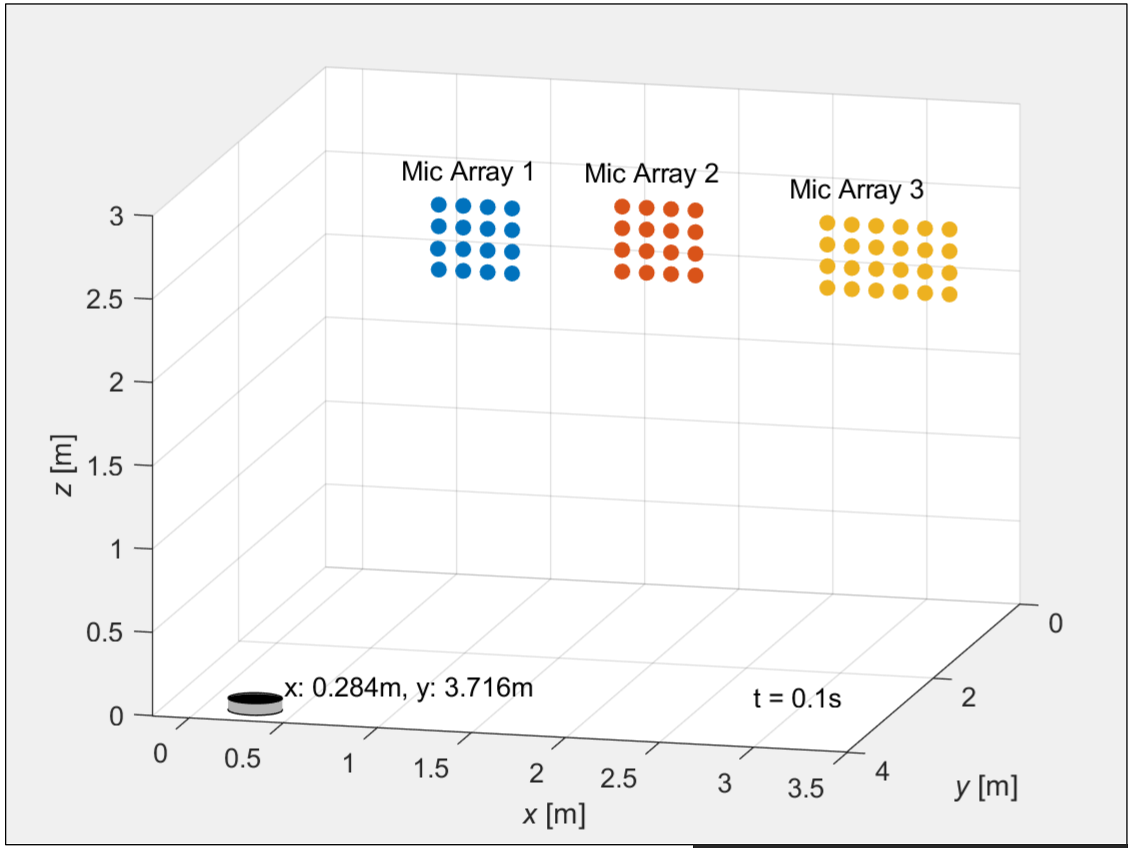
MC Localization Dataset II – How can we generate the Ground Truth?



MC Localization Dataset II – Ground Truth Visualization

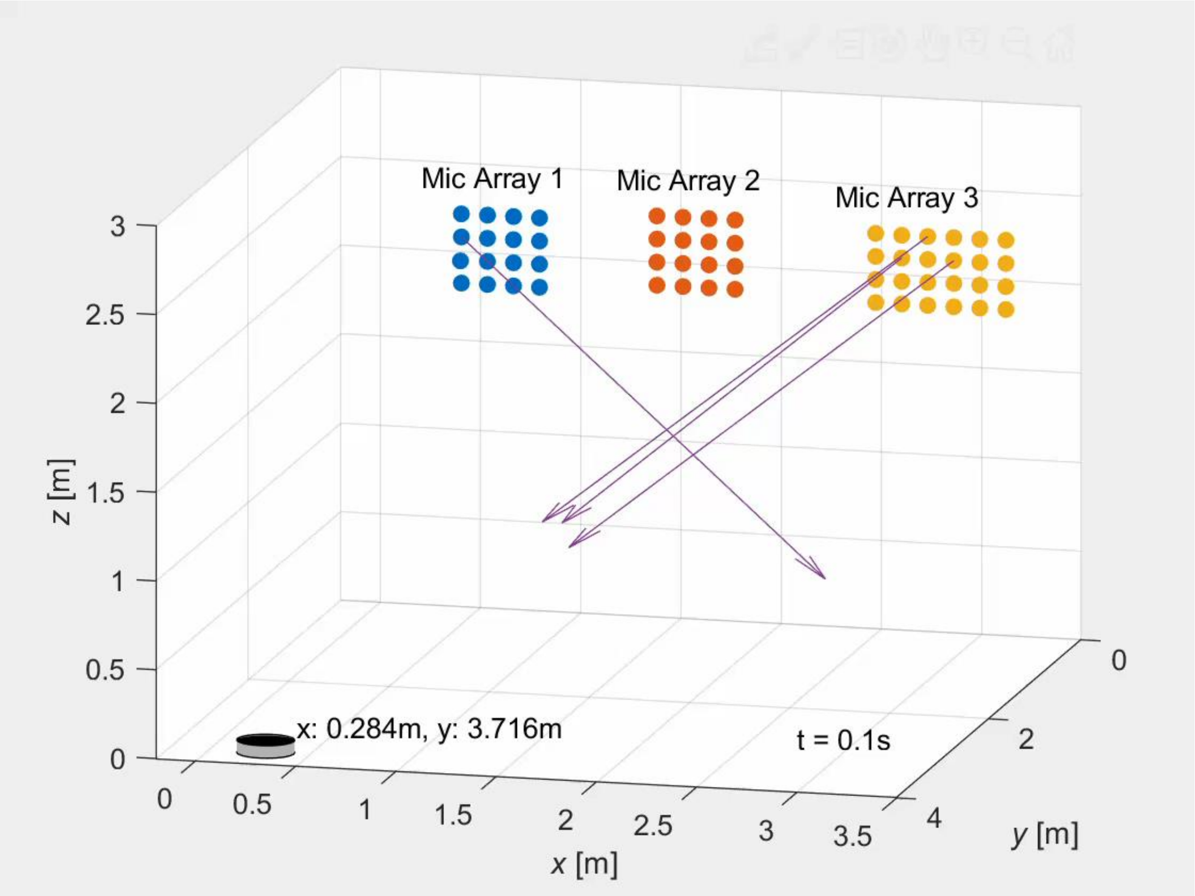


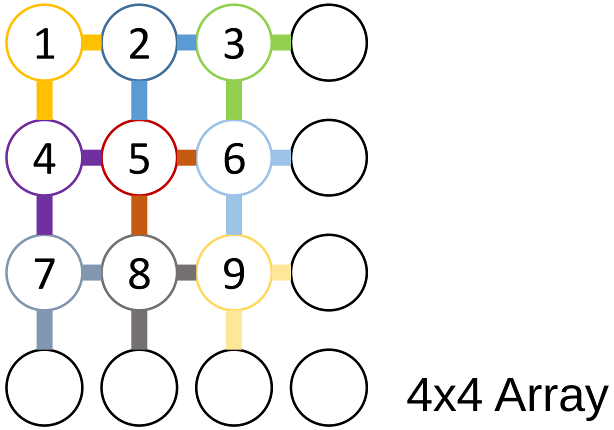
GT Video Realworld



GT Video 3D Model

MC Localization Dataset II – Location Determination Results

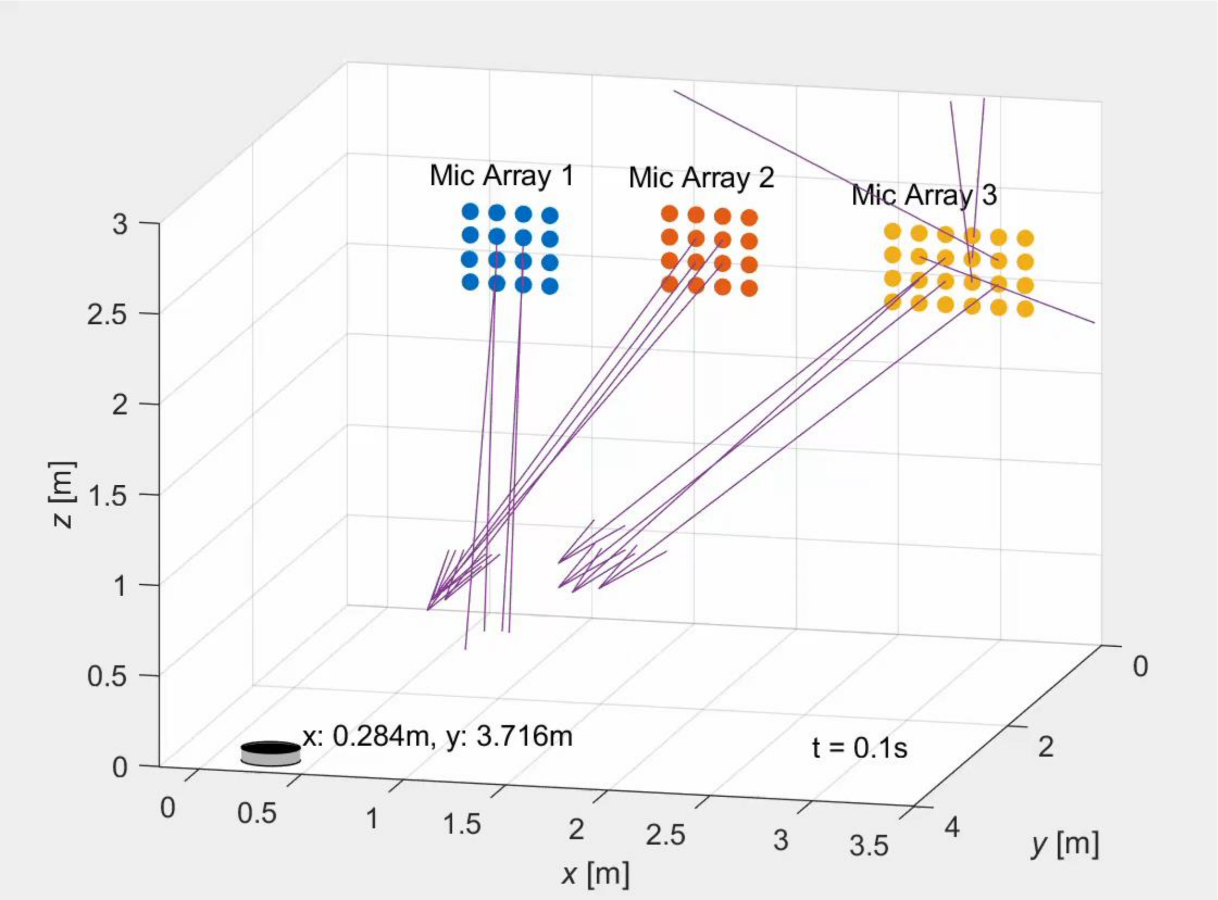


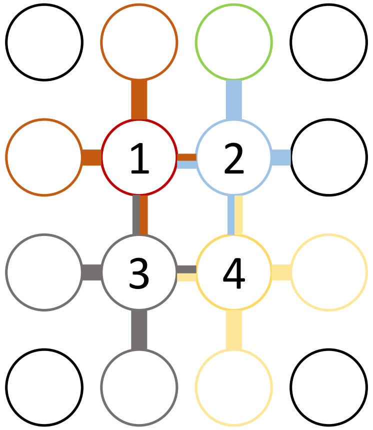


Localization:

- only direct neighbor → 9 × L-shape mic pairs
- only vertical angles considered 0° <= ϕ_{vert} <= 90°

MC Localization Dataset II – Location Determination Results





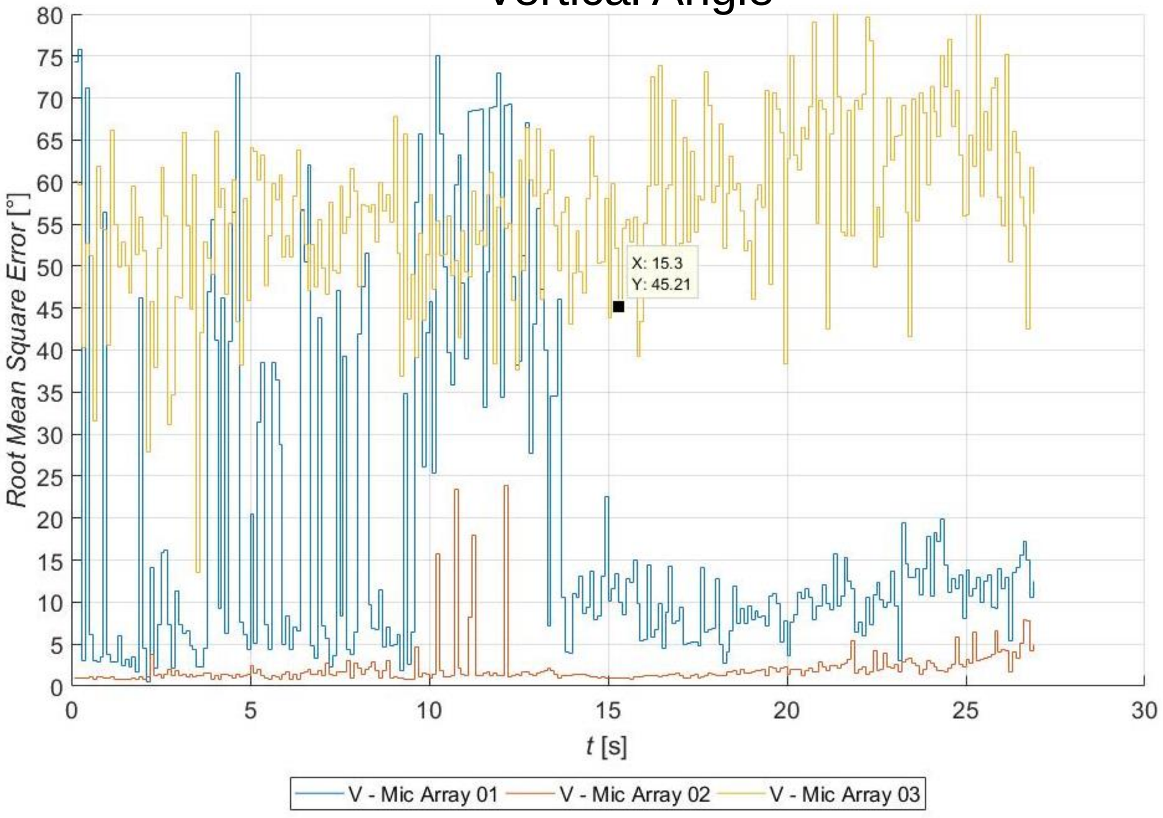
4x4 Array

Localization:

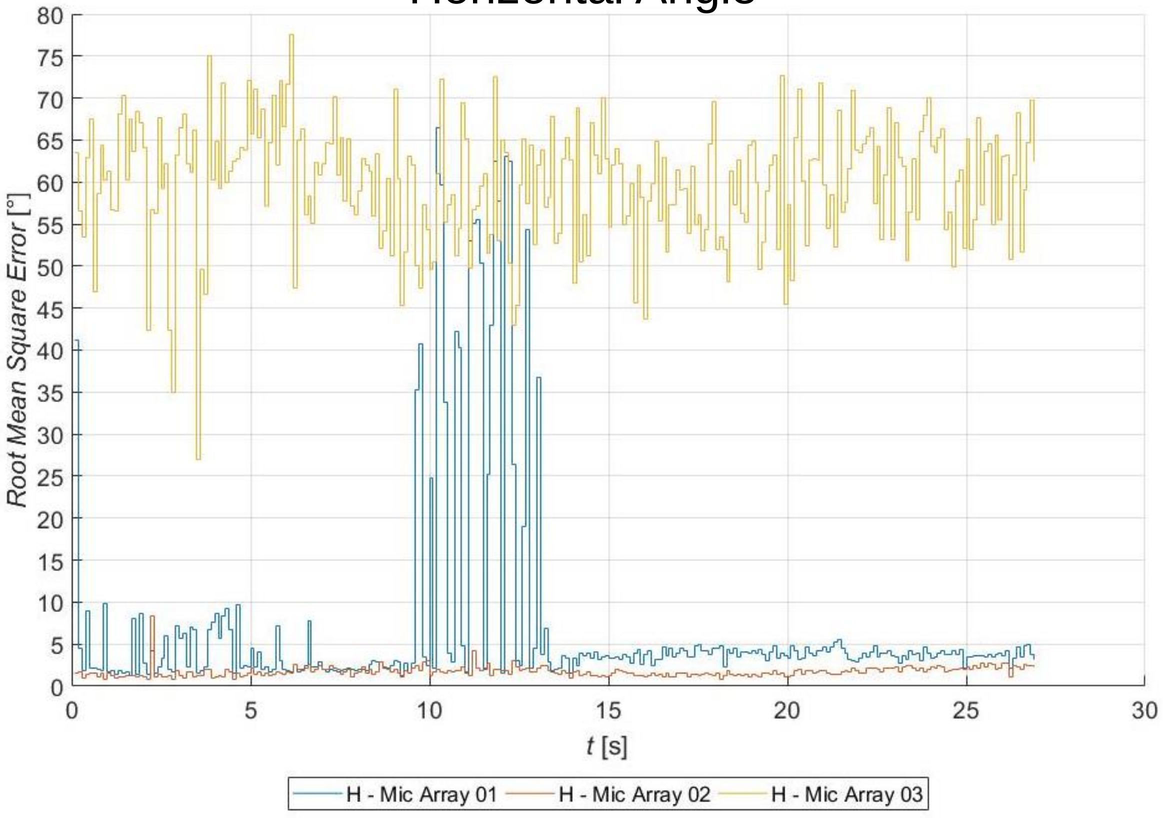
- only direct neighbor → 4 × X-shape mic pair
- all angles considered 0° <= ϕ_{vert} <= 90°

Evaluation of Array 1 vs. Array 2 vs. Array 3

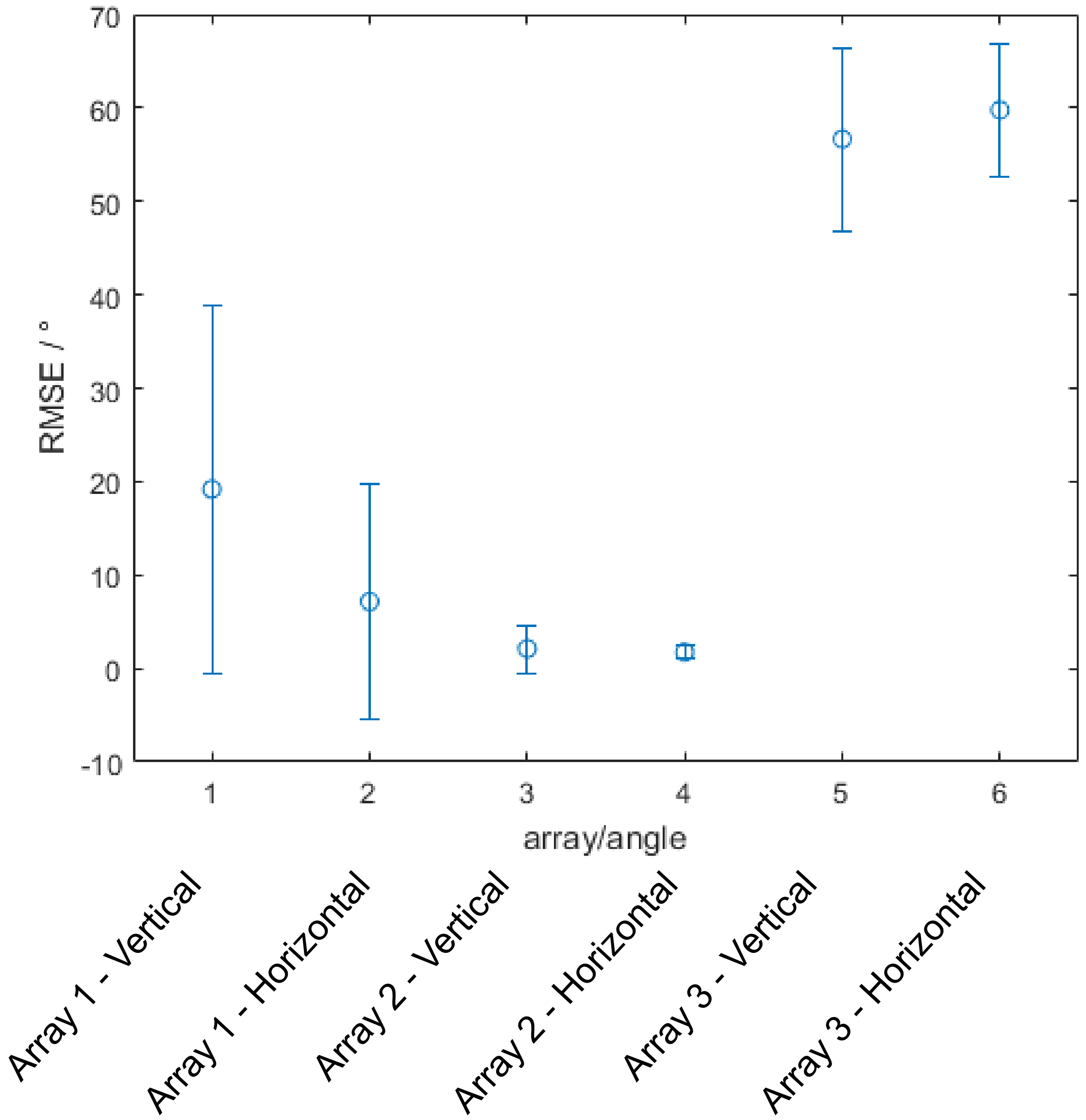
Vertical Angle

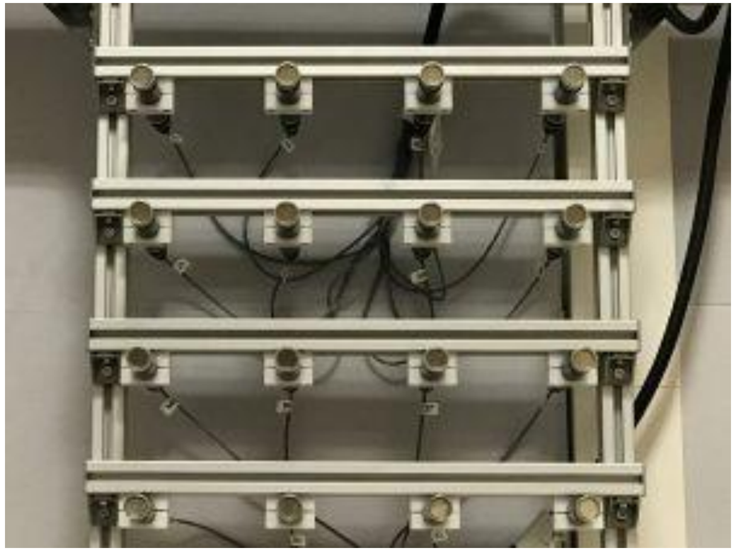


Horizontal Angle



Evaluation of Array 1 vs. Array 2 vs. Array 3





→ best results for cardioid microphones

Implementation Details

Data Processing Task	Essential (Matlab) functions*	Matlab Toolboxes
Camera Calibration	Camera Calibrator App	Computer Vision
Rectification	undistortImage	Image Processing
Image Annotation (Ground Truth)	imageLabeler (App)	Computer Vision
Coordinate Transformation	Cp2tform	Image Processing
Time Delay of Arrival	Xcorr	Signal Processing
Direction of Arrival	Cosine/Algebra	
Evaluation/Regression	Fit, (Goodnes of Fit)	Curve Fitting
Visualisation	scatter3	-

*Matlab 2018a

Outlook

- Sensor Fusion with (Deep Learning based) Localized Objects from Video Material
- Publication of results and source code
- Intregration into lecture/turorials (Matlab Live Editor)
- Optimization of localization
  - Beamforming
  - Geometry
  - Deep Learning
- Search (Industrial) Cooperations

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References

[1] J. York, 'Angle Of Arrival.' [Online: last accessed 16.03.2019]. https://www.ese.wustl.edu/~nehorai/josh/students.cec.wustl.edu/_jly1/doa.html.

[2] J. York, 'Cooridinate Derivation '(x,y)'.' [Online: last accessed 16.03.2019]. https://www.ese.wustl.edu/~nehorai/josh/students.cec.wustl.edu/_jly1/posderivation.html.

[3] Y. Zhang, Waleed, and H. Abdulla, 'A Comparative Study of Time-Delay Estimation Techniques Using Microphone Arrays', in The University of Auckland, School of Engineering Report, Auckland, New Zealand, 2005, vol. 619.

[4] H. Wang et al., 'Acoustic sensor networks for woodpecker localization', in Proc.SPIE, 2005, vol. 5910.

[5] C.-E. Chen, A. M. Ali, and H. Wang, 'Design and Testing of Robust Acoustic Arrays for Localization and Enhancement of Several Bird Sources', in Proceedings of the 5th International Conference on Information Processing in Sensor Networks, New York, NY, USA, 2006, pp. 268–275.

[6] J. Lanslots, F. Deblauwe, and K. Janssens, 'Selecting sound source localization techniques for industrial applications', Sound Vib., vol. 44, no. 6, p. 6, 2010.

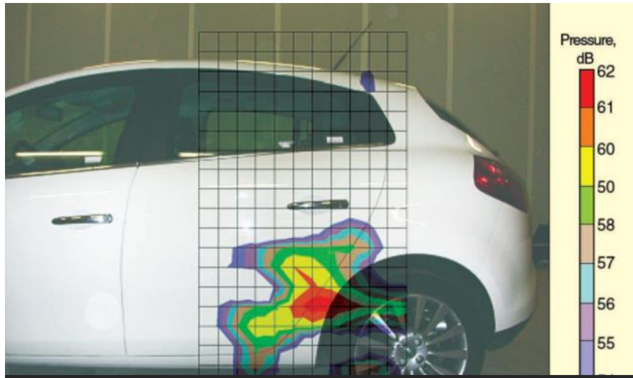
[7] M. Basiri, F. Schill, P. U.Lima, and D. Floreano, 'Localization of emergency acoustic sources by micro aerial vehicles', J. Field Robot., vol. 35, no. 2, pp. 187–201, Mar. 2018.

[8] S. V. Sibanyoni, D. T. Ramotsoela, B. J. Silva, and G. P. Hancke, 'A 2-D Acoustic Source Localization System for Drones in Search and Rescue Missions', IEEE Sens. J., vol. 19, no. 1, pp. 332–341, Jan. 2019.

3D Acoustic Source Localization – What is it good for?

- Wang et al. 2005, ‘Acoustic sensor networks for ***woodpecker localization***’ [4]
- Chen et al. 2006, ‘Design and Testing of Robust Acoustic Arrays for Localization and Enhancement of Several ***Bird Sources***’ [5]
- Lanslots et al. 2010, ‘Selecting sound source localization techniques for ***industrial applications***’ [6]
- Basiri et al. 2018, ‘Localization of ***emergency*** acoustic sources by micro aerial vehicles’ [7]
- Sibanyoni et al. 2019, ‘A 2-D Acoustic Source Localization System for ***Drones in Search and Rescue*** Missions’ [8]


Micro Aerial Vehicle [7]



Door slam [6]