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(W)earable Microphone Array and Ultrasonic Echo Localization for Coarse Indoor Environment Mapping

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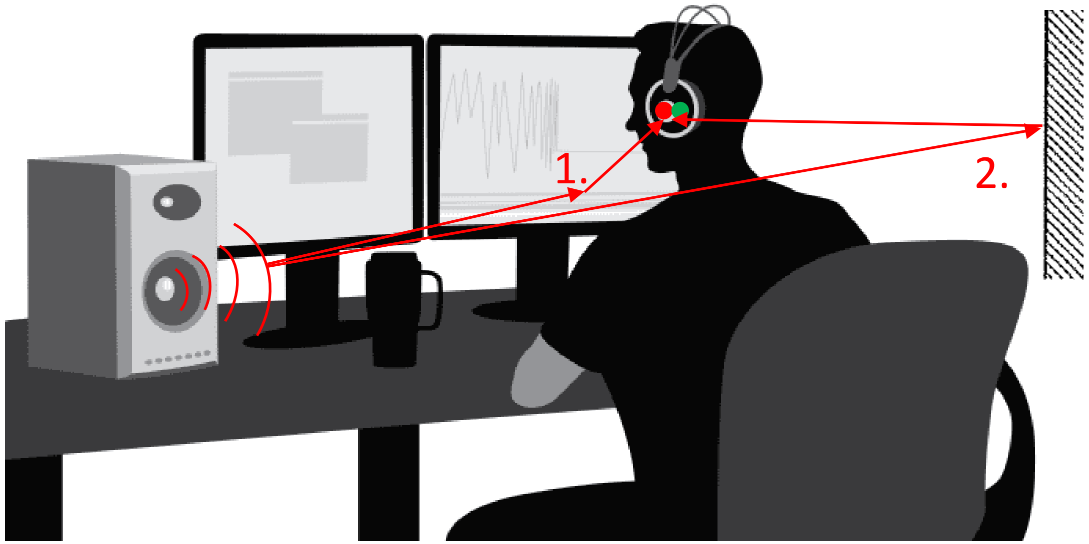
Reflection-based acoustic tracking



1. Monitor reflection: orientation ψ_1 and position xyz_1
2. Wall reflection: orientation ψ_2 and position xyz_2

⬇

Track Head Position via Headset Microphones

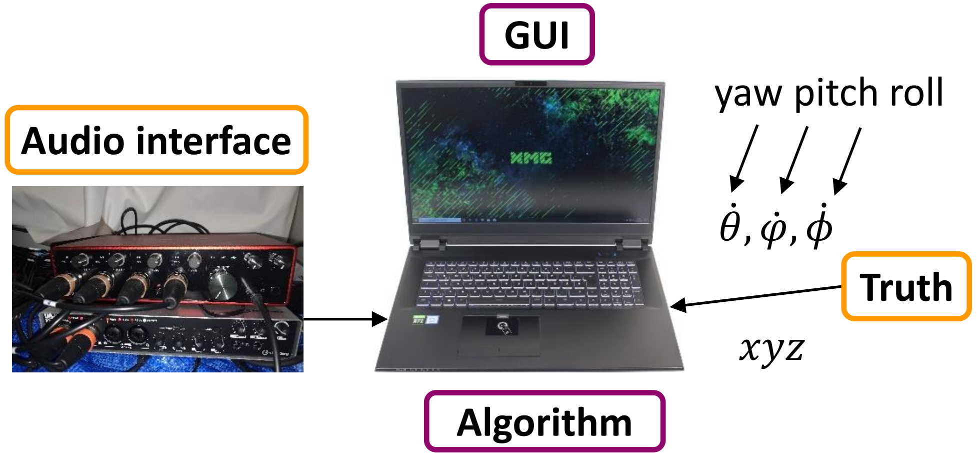
State of the art

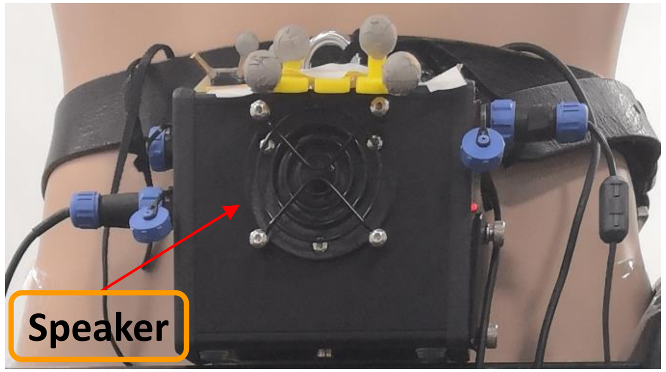
- Localization with external sound beacons:
  - Error up to 5° / 5 cm (e.g. Blanco et al., 2008)

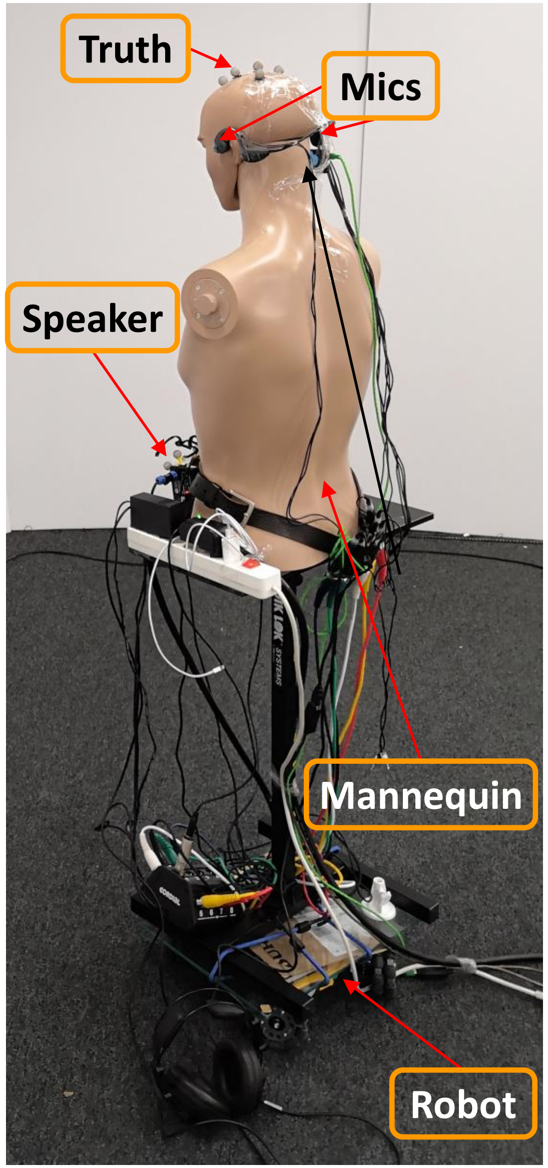
- Reflection-based acoustic SLAM:
  - 1st computer simulation study (Krekovic et al., 2016)
  - 4 walls, no curved wall reflections or scattering
  - Unsolved measurement challenges

- Our past work:
  - Inside-out stationary differential head tracking
  - Free room shape, 15 - 30° horizontal error

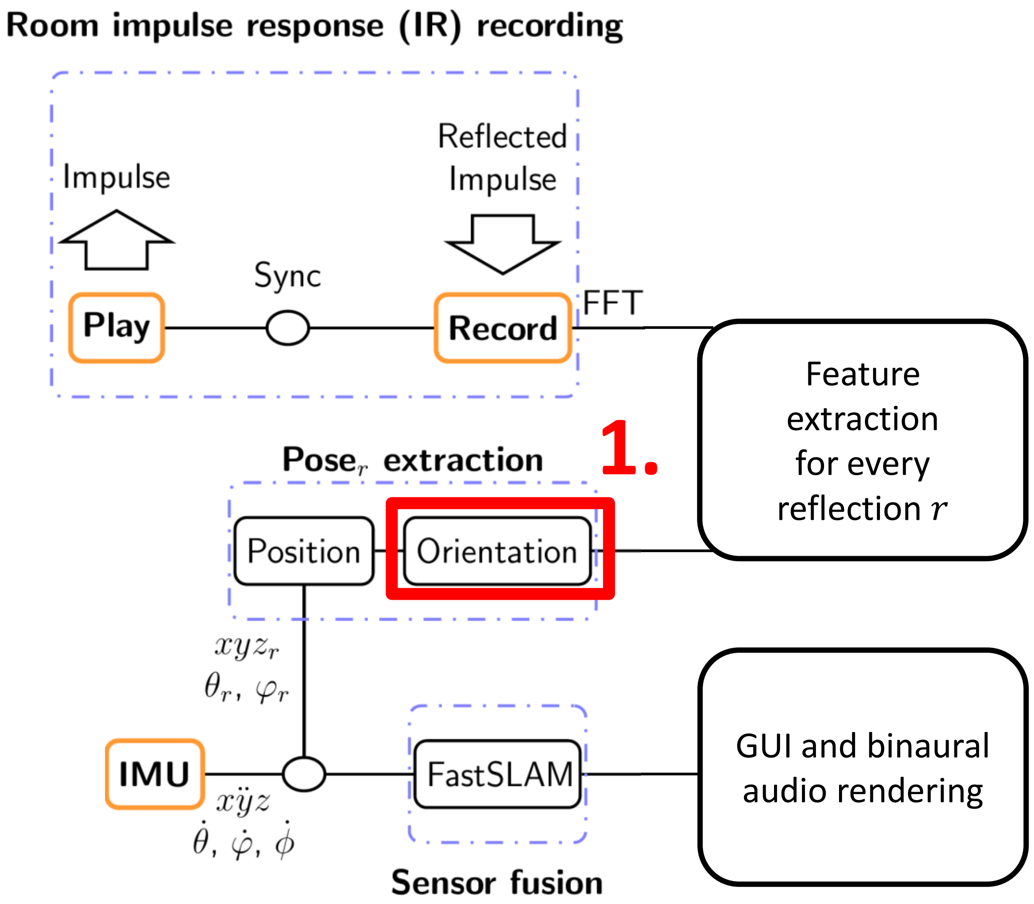
Our hardware

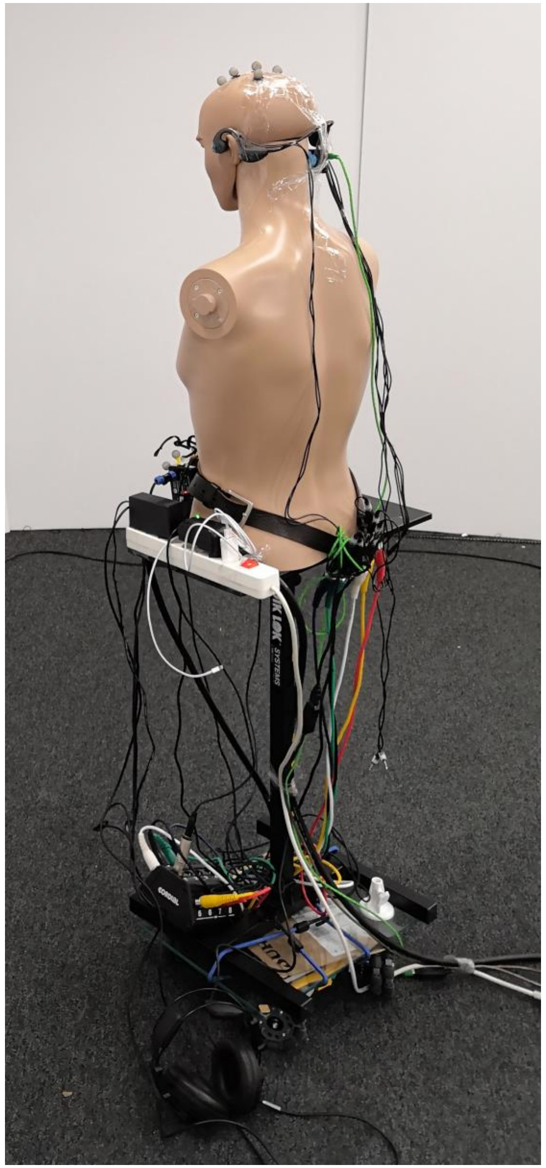




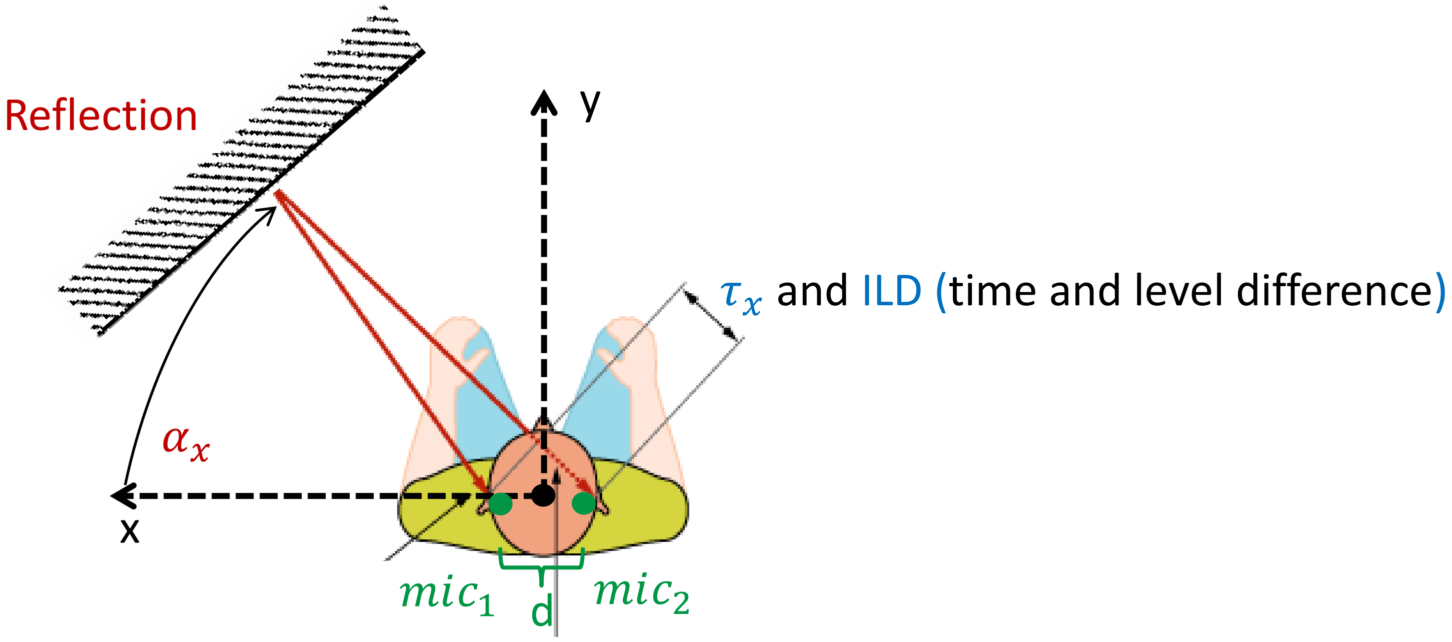


Reflection orientation estimation





Method

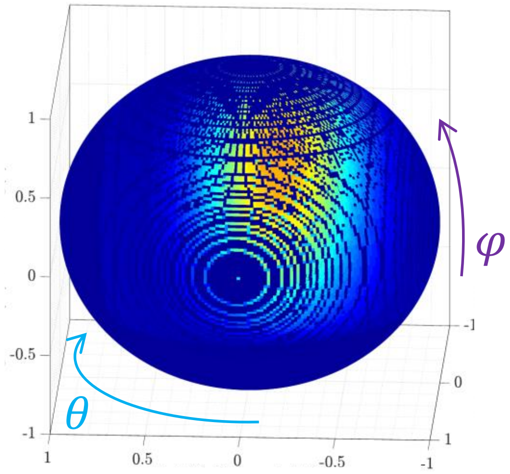


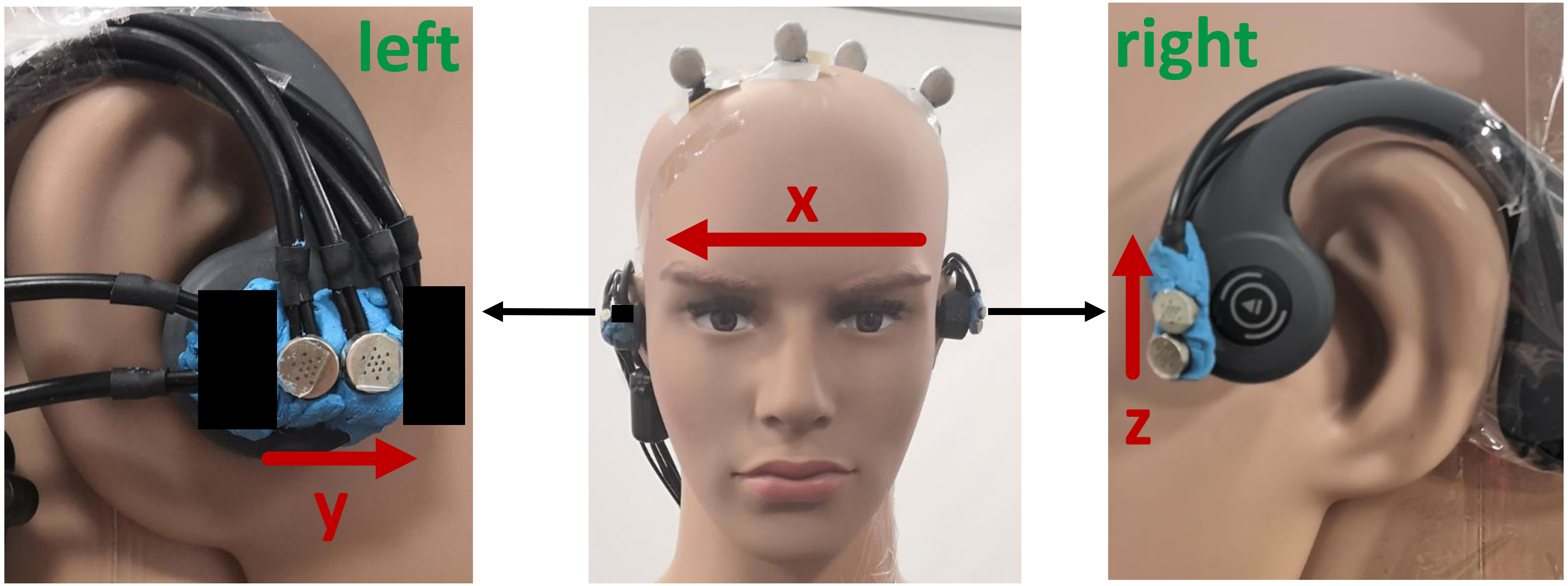
τ_x characteristic for incidence angle α_x:

$$\tau_x = \frac{d}{SoS} \cdot cos(\alpha_x)$$

Method

1. Pair-wise cross-correlation $R_{mic_1,mic_2}(\tau)$ in y and z dimension
2. x-dimension: synthesize time-of-arrival τ_x from ILD
3. Convert time-of-arrivals $\boldsymbol{\tau}_{x,y,z}$ to incidence probability $p(\boldsymbol{\alpha})$
4. Map Cartesian propablity $p(\boldsymbol{\alpha})$ to spherical propablity $p(\theta, \varphi)$

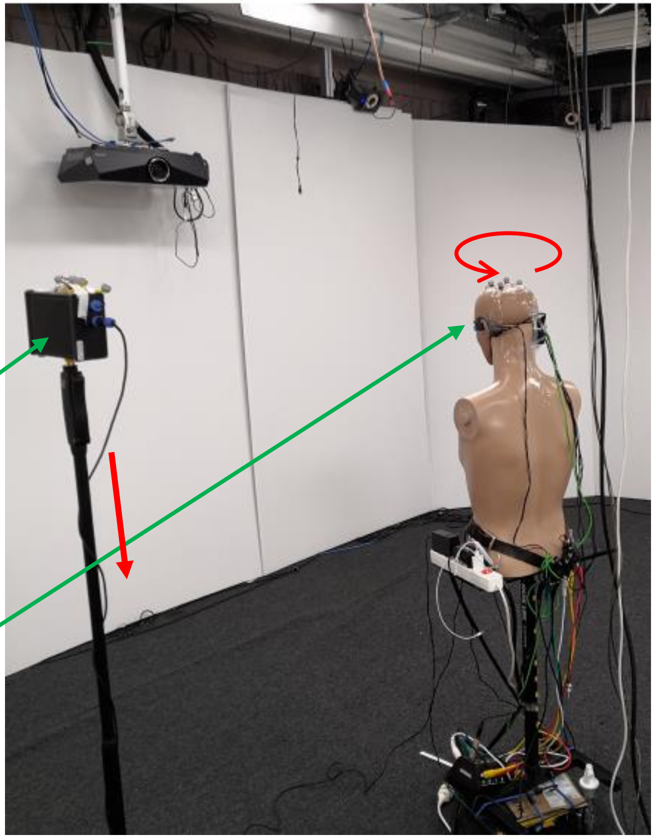


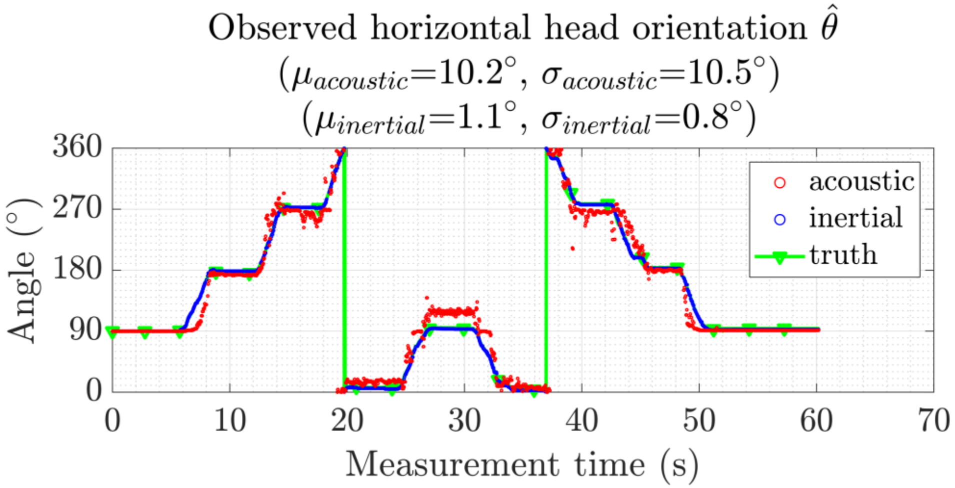


Evaluation

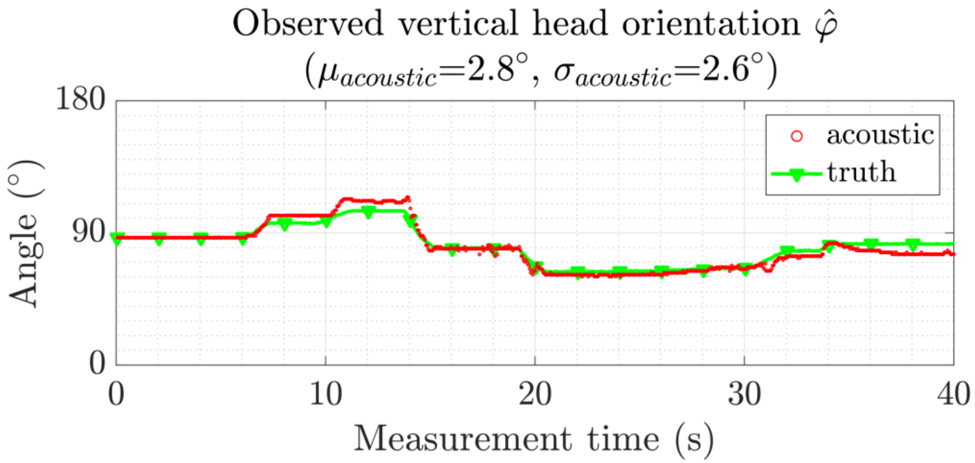
Speaker

Mics
IMU



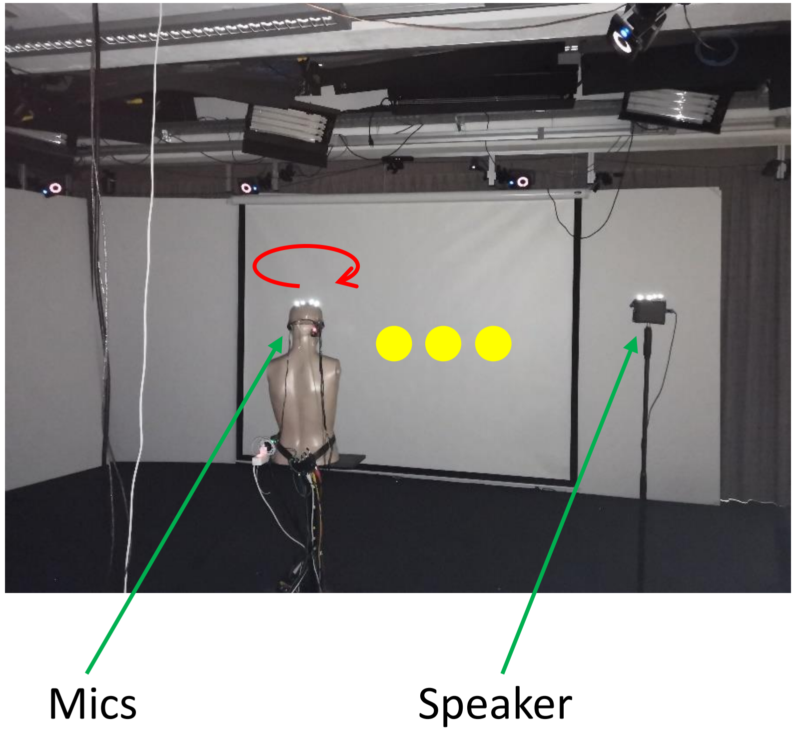


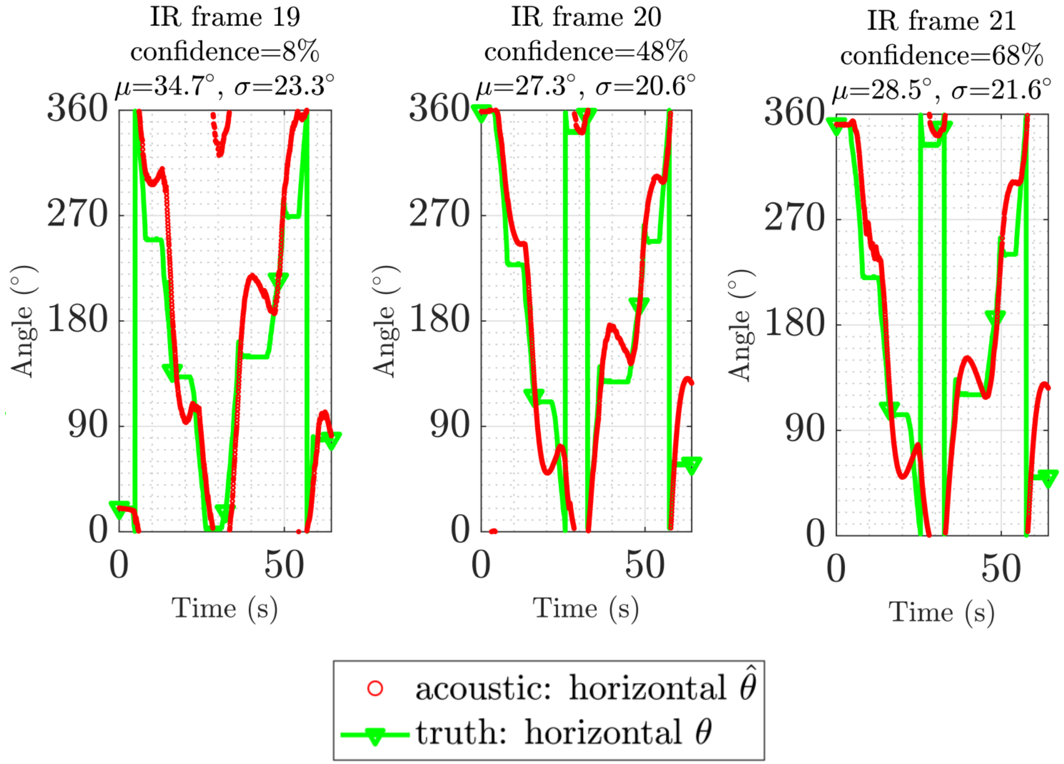
Horizontal head orientation



Vertical head orientation

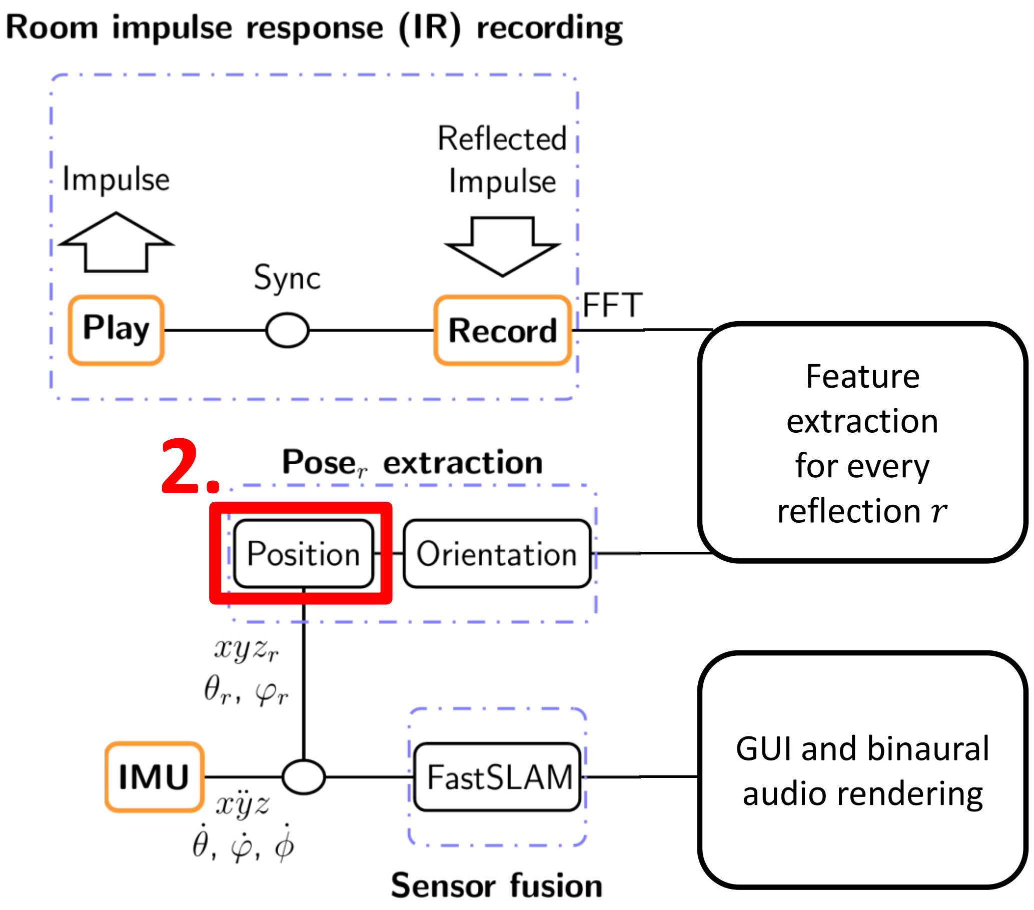
Evaluation: planar reflection

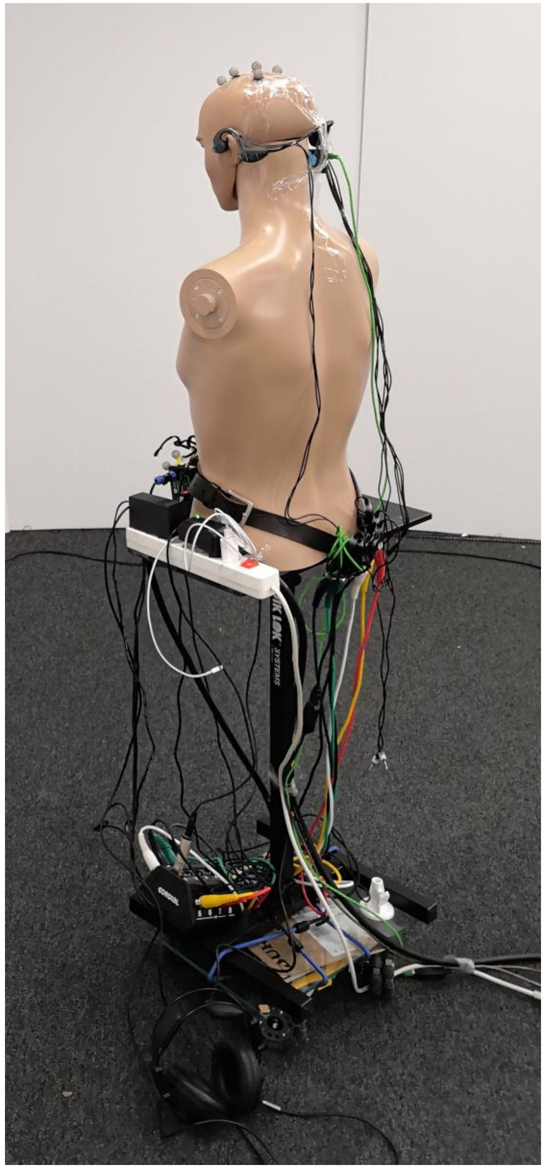




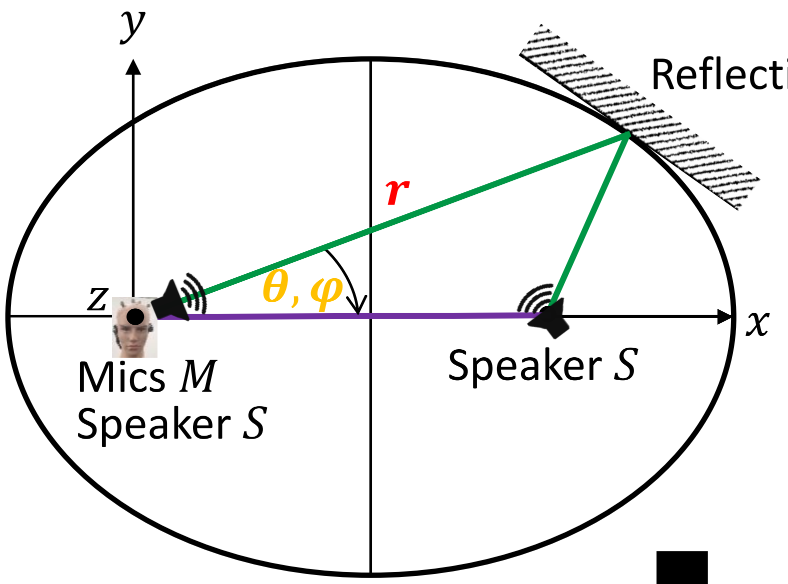
Absolute acoustic reflection orientation estimate

Reflection position estimation





Method



We search:
Reflection distance r

We know:
Time of arrivals: $ToA_{\overline{SRM}}$, $ToA_{\overline{SM}}$
Incidence angles: θ, φ

General solution:

$r = \frac{a\,(1 - e^2)}{1 + e \cdot cos\theta \; cos\varphi} \cdot SoS$ with semi-major axis $a = \frac{ToA_{\overline{SRM}}}{2}$ and eccentricity $e = \frac{ToA_{\overline{SM}}}{2a}$

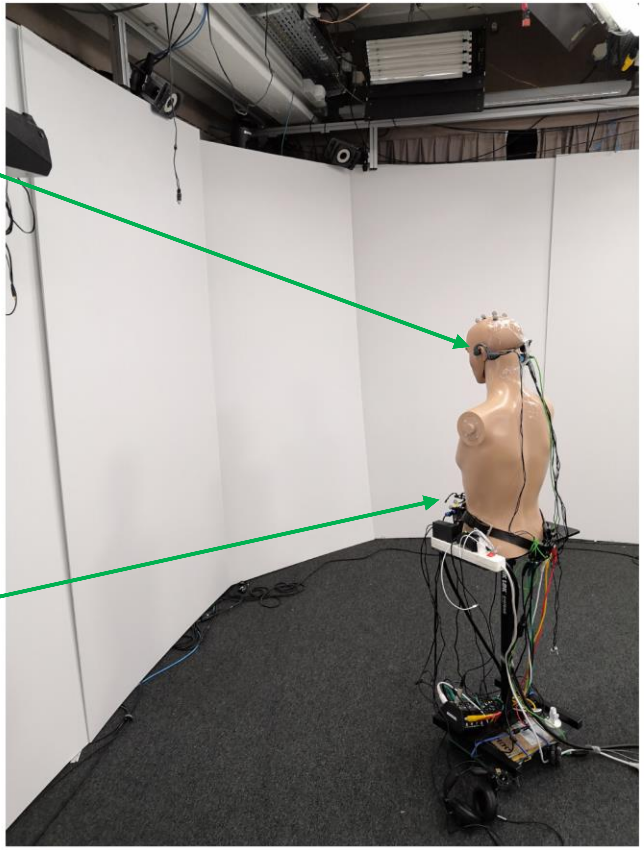
Special solution ($ToA_{\overline{SM}} = 0$):

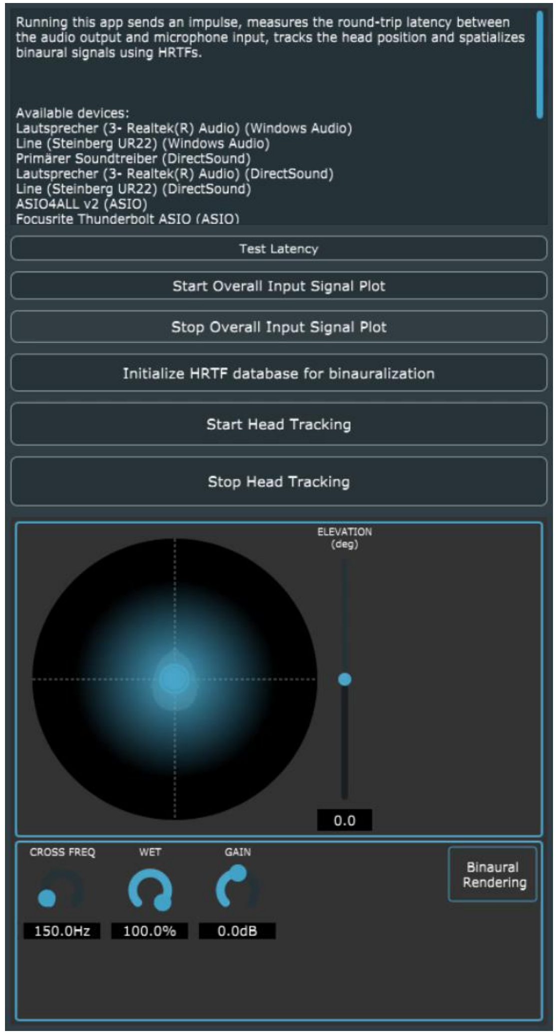
$r = \frac{ToA_{\overline{SRM}}}{2} \cdot SoS$ (conventional sonar sensing equation)

Evaluation

Mics

Speaker





Conclusion

- We formulated:
  - Steps towards reflection-based acoustic-inertial SLAM
  - New techniques for reflection orientation & position sensing

- We achieve:
  - Head tracking with 2 microphones per ear at 50 Hz update rate
  - Horizontal tracking error: 20 - 30°
  - Environment mapping of planar and curved walls

- Future work:
  - Embed in noise cancellation headphones, 6 DOF, loop closing
  - Explore applications outside the presented domain

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