

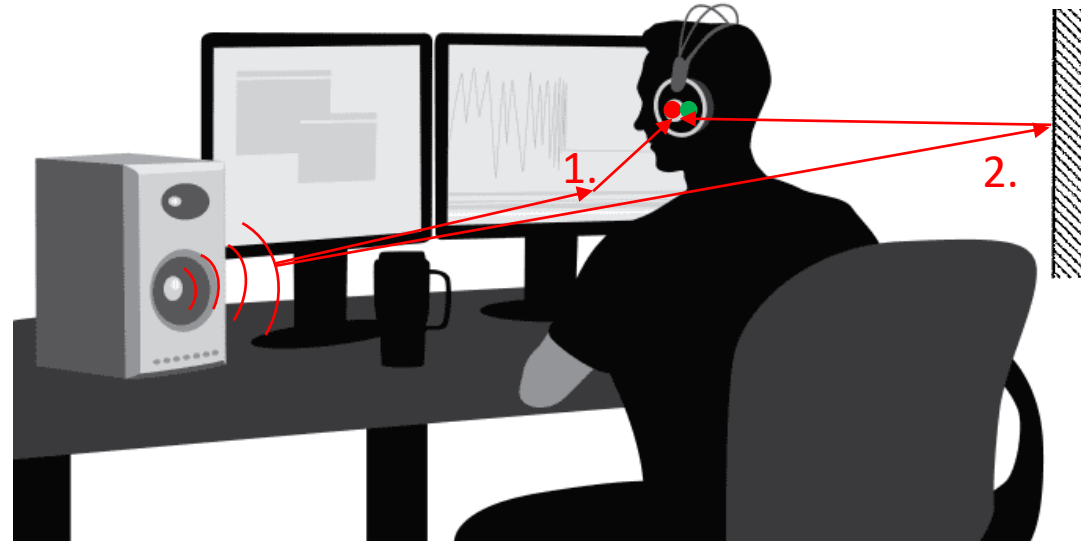


(W)earable Microphone Array and Ultrasonic Echo Localization for Coarse Indoor Environment Mapping

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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



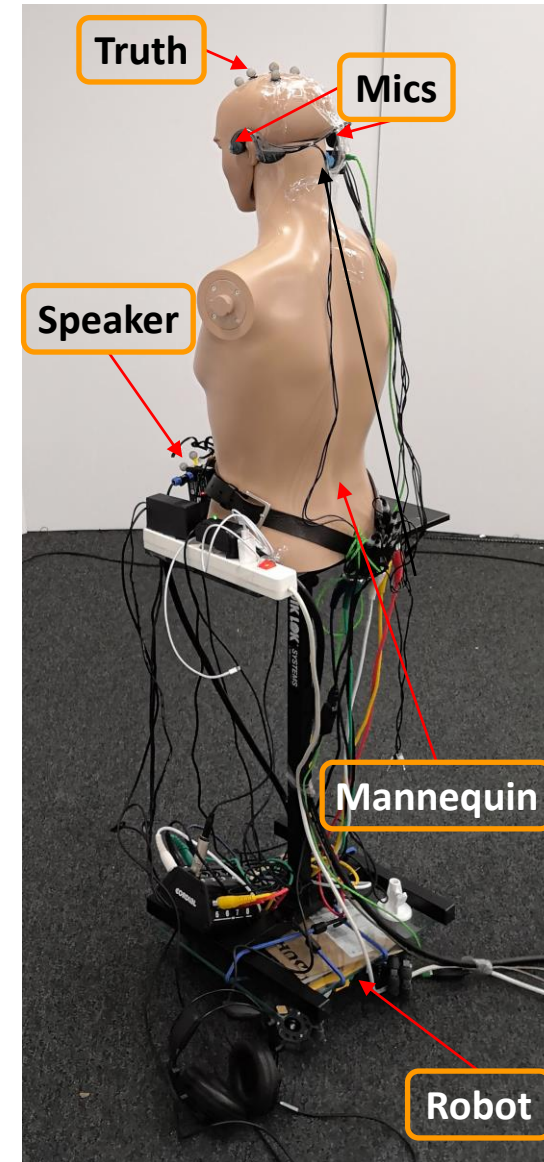
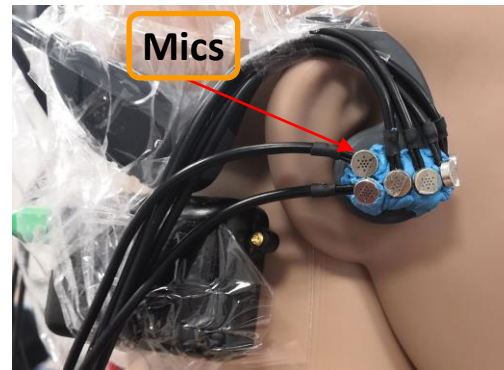
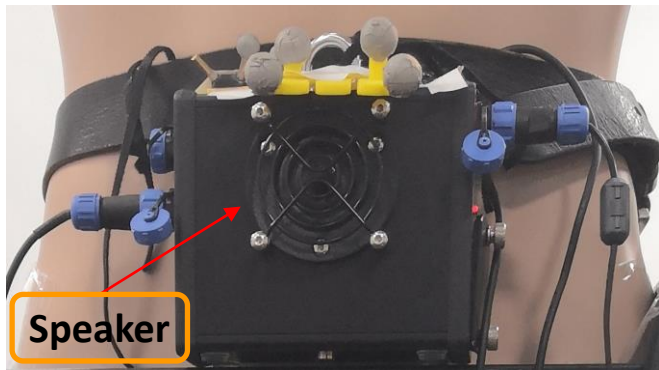
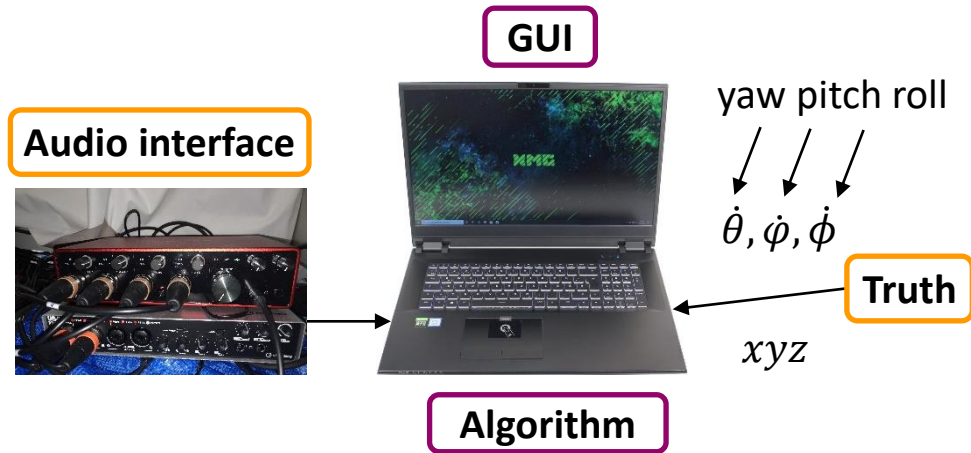
Track Head Position via Headset Microphones

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

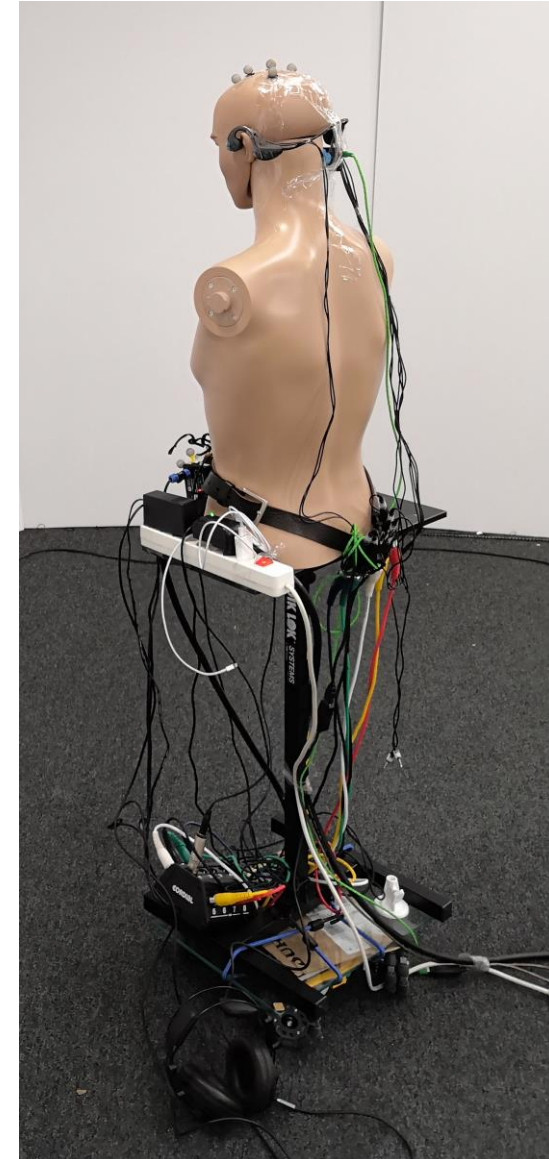
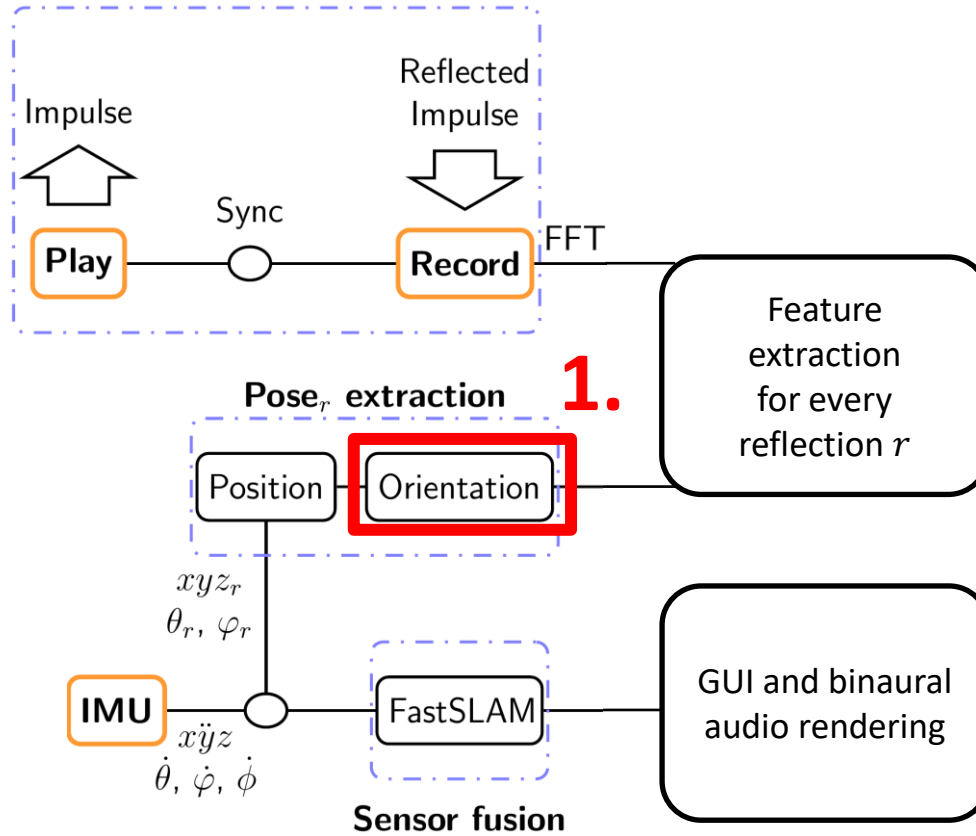


Our hardware

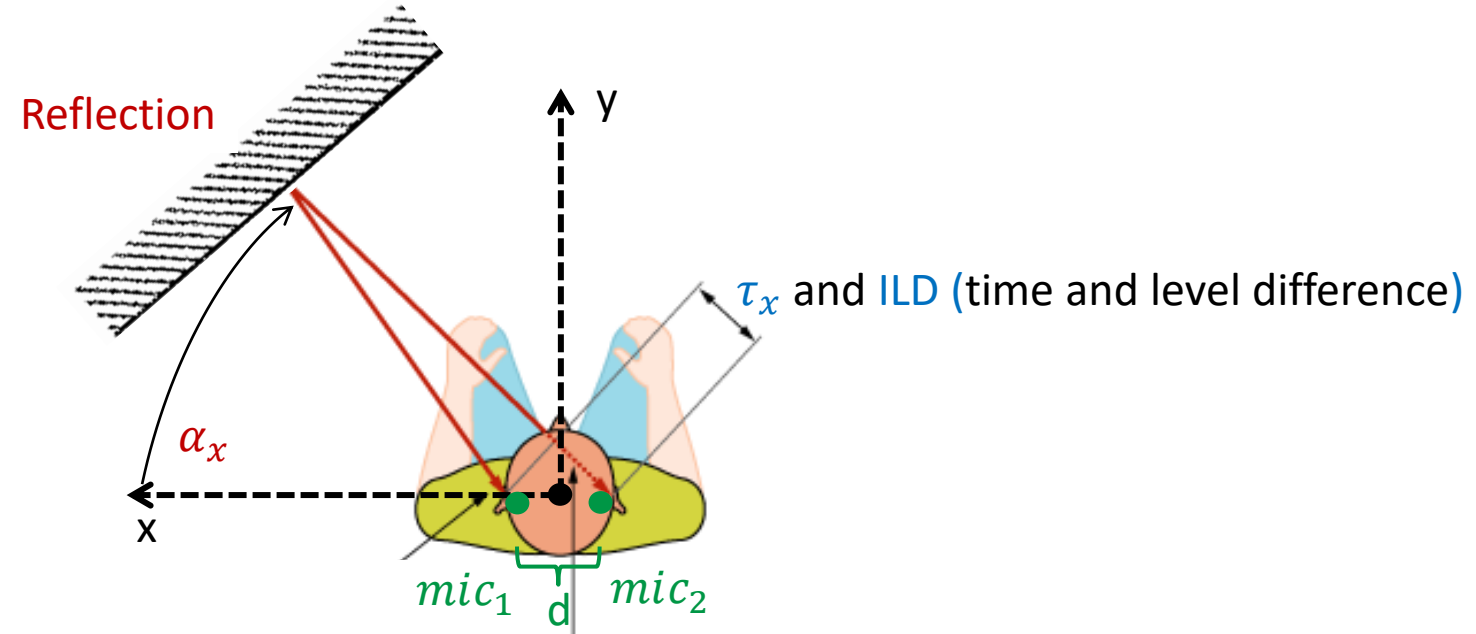


Reflection orientation estimation

Room impulse response (IR) recording



Method

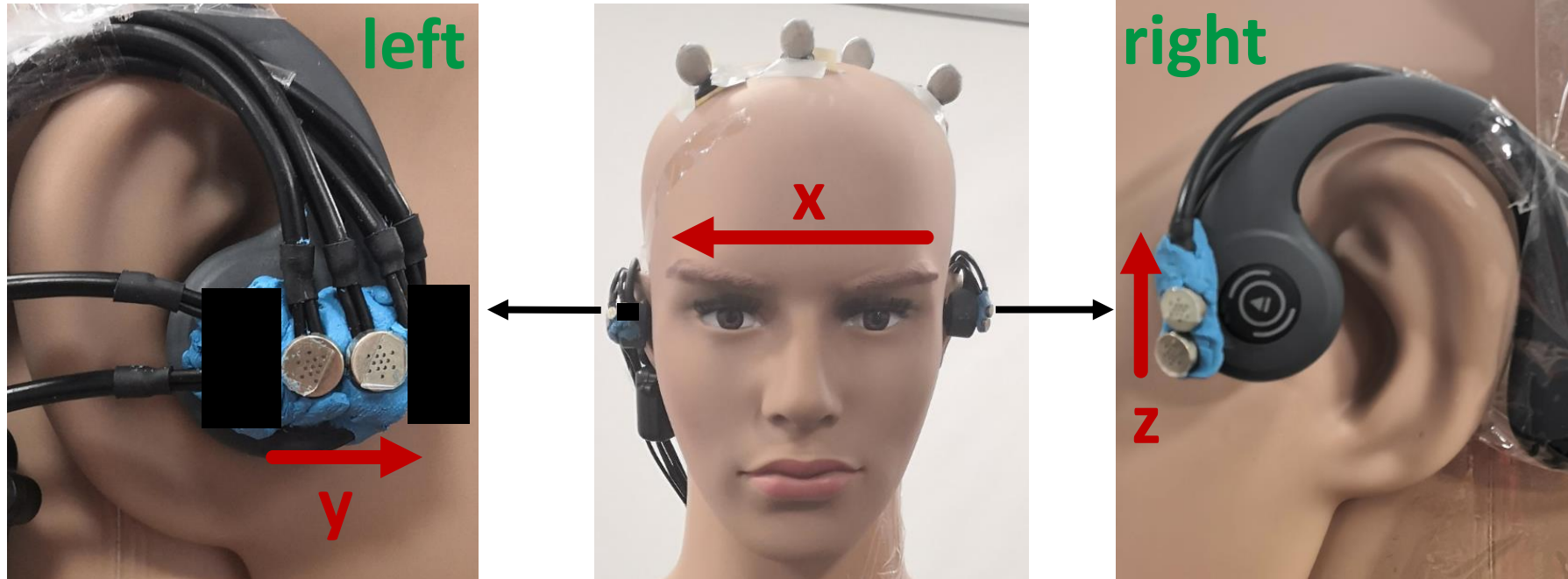
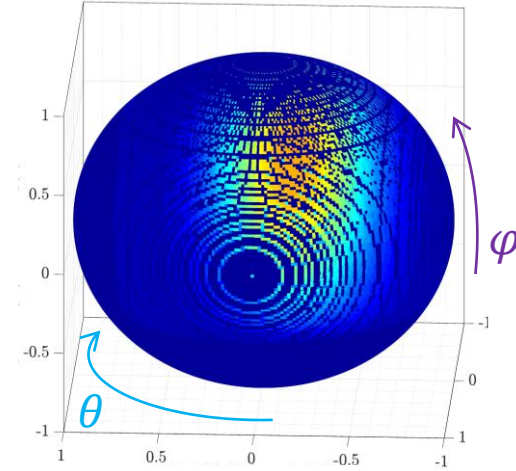


τ_x characteristic for incidence angle α_x :

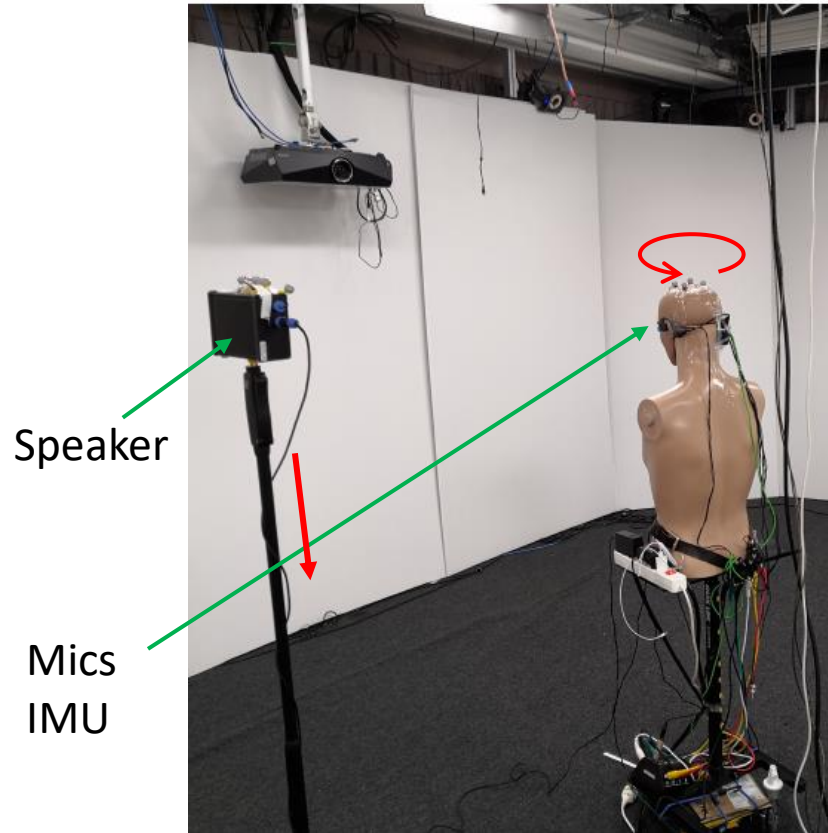
$$\tau_x = \frac{d}{SOS} \cdot \cos(\alpha_x)$$

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 $\tau_{x,y,z}$ to incidence probability $p(\alpha)$
4. Map Cartesian propablity $p(\alpha)$ to spherical propablity $p(\theta, \varphi)$



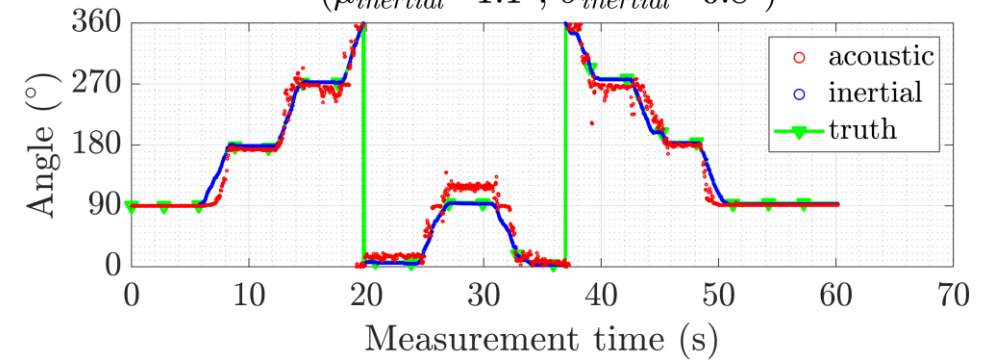
Evaluation



Observed horizontal head orientation $\hat{\theta}$

$(\mu_{acoustic}=10.2^\circ, \sigma_{acoustic}=10.5^\circ)$

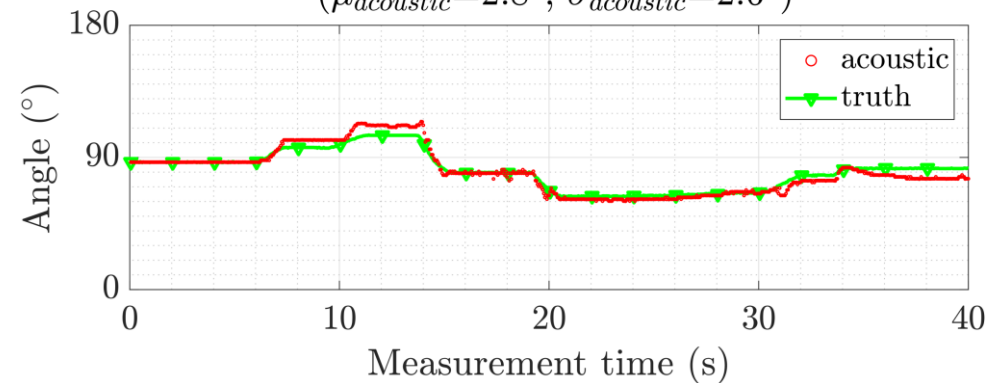
$(\mu_{inertial}=1.1^\circ, \sigma_{inertial}=0.8^\circ)$



Horizontal head orientation

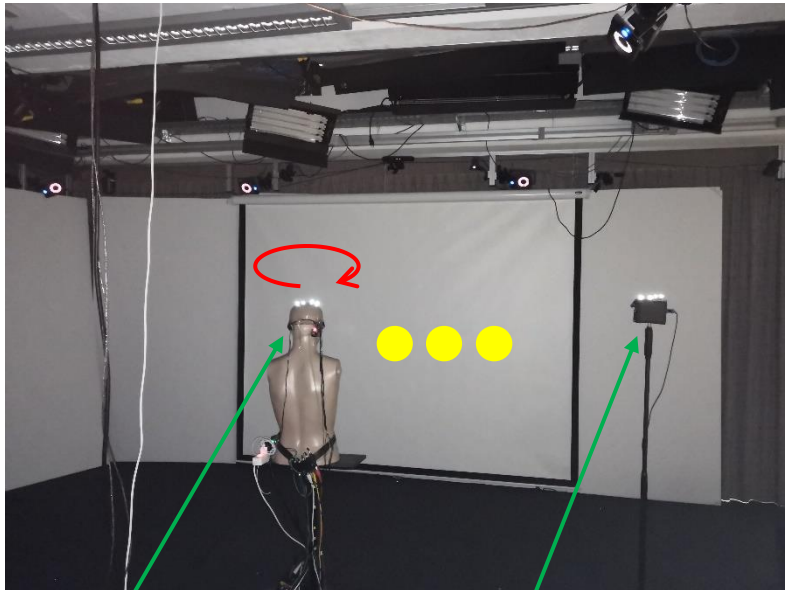
Observed vertical head orientation $\hat{\varphi}$

$(\mu_{acoustic}=2.8^\circ, \sigma_{acoustic}=2.6^\circ)$



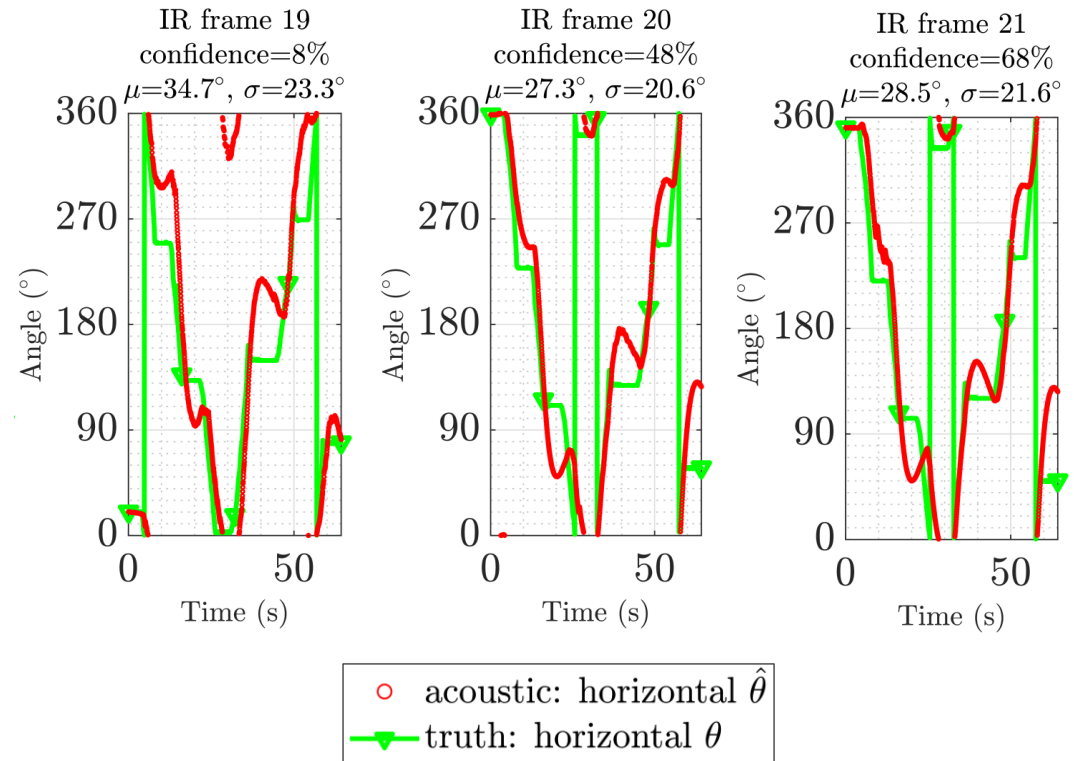
Vertical head orientation

Evaluation: planar reflection



Mics

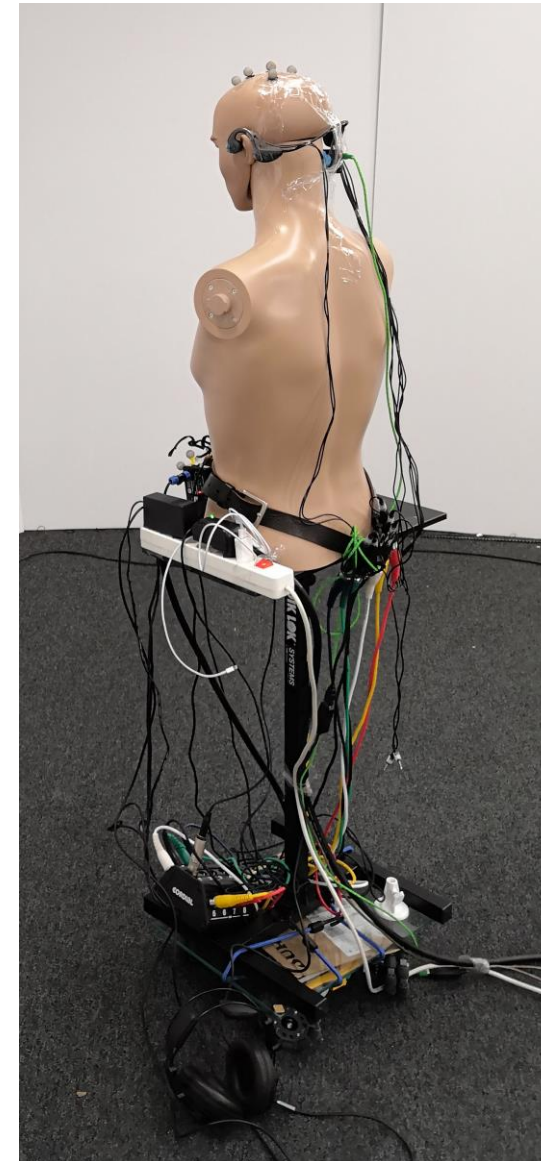
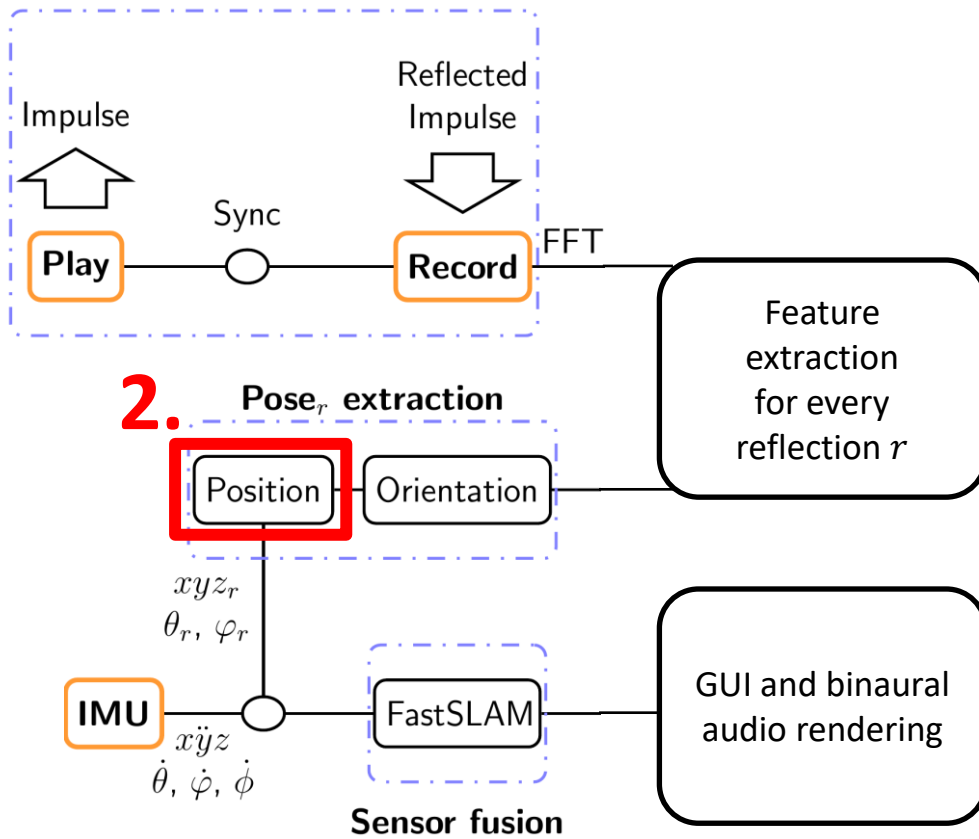
Speaker



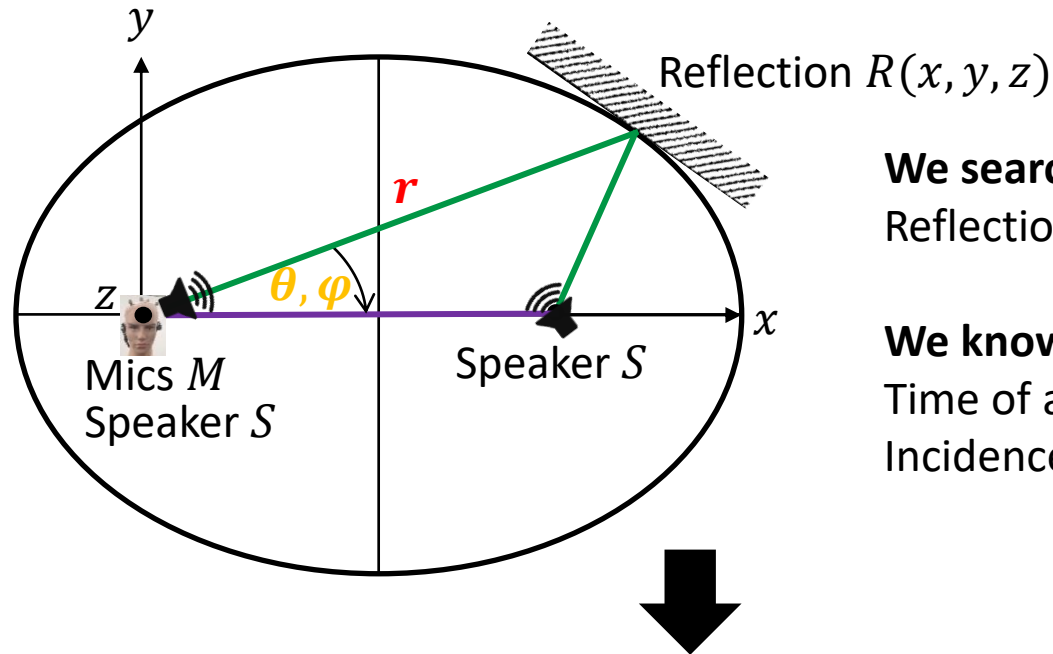
Absolute acoustic reflection orientation estimate

Reflection position estimation

Room impulse response (IR) recording



Method



We search:

Reflection distance r

We know:

Time of arrivals: $ToA_{\overline{SRM}}$, $ToA_{\overline{SM}}$

Incidence angles: θ, φ

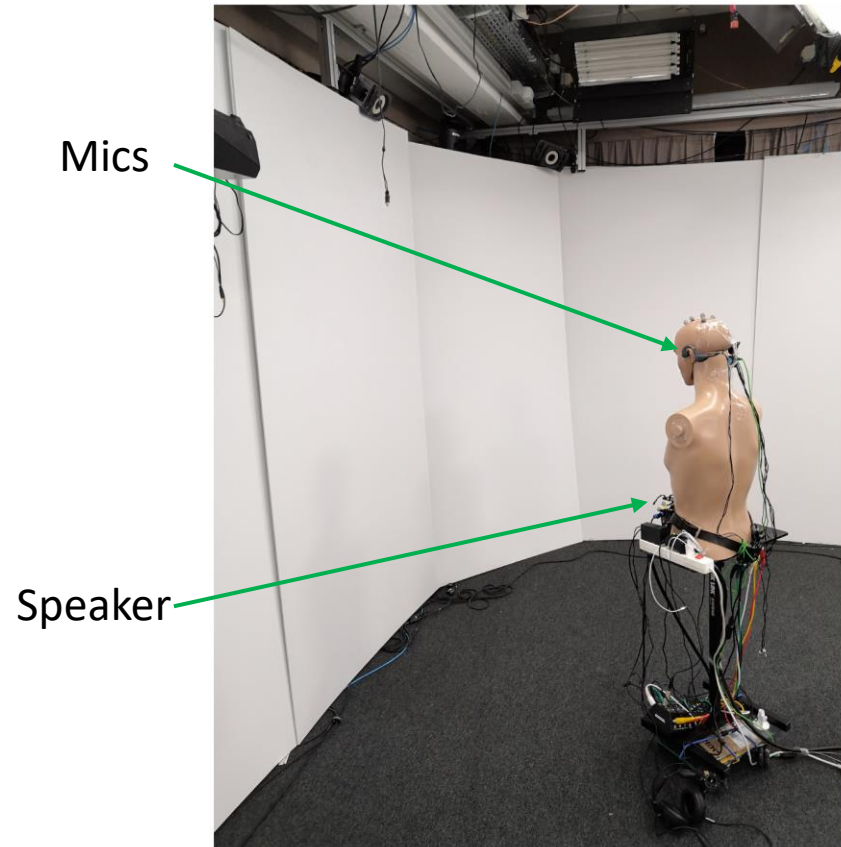
General solution:

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

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

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

Evaluation



Running this app sends an impulse, measures the round-trip latency between the audio output and microphone input, tracks the head position and spatializes binaural signals using HRTFs.

Available devices:
Lautsprecher (3- Realtek(R) Audio) (Windows Audio)
Line (Steinberg UR22) (Windows Audio)
Primärer Soundtreiber (DirectSound)
Lautsprecher (3- Realtek(R) Audio) (DirectSound)
Line (Steinberg UR22) (DirectSound)
ASIO4ALL v2 (ASIO)
Focusrite Thunderbolt ASIO (ASIO)

Test Latency

Start Overall Input Signal Plot

Stop Overall Input Signal Plot

Initialize HRTF database for binauralization

Start Head Tracking

Stop Head Tracking

ELEVATION (deg)

CROSS FREQ 150.0Hz WET 100.0% GAIN 0.0dB

Binaural Rendering

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

References:

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