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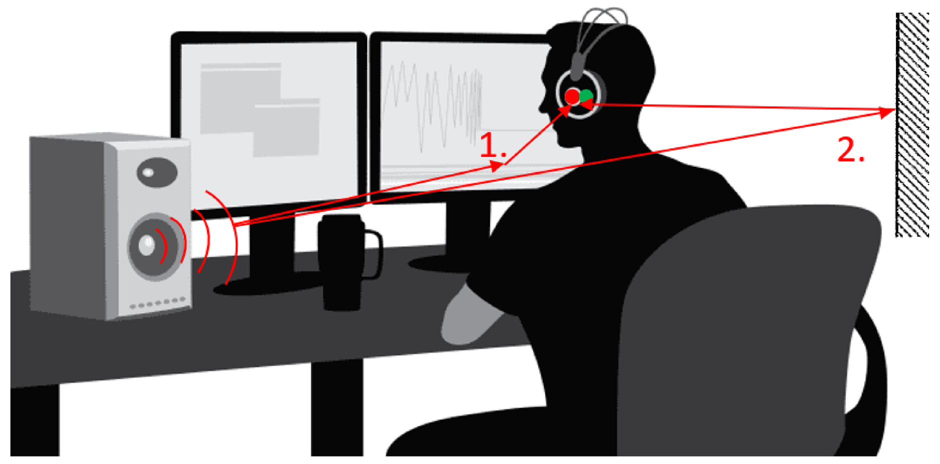
(W)earable Microphone Array and Ultrasonic Echo Localization for Coarse Indoor Environment Mapping

Felix Pfreundtner, Jing Yang, Gábor Sörös
Department of Computer Science, ETH Zurich, Switzerland

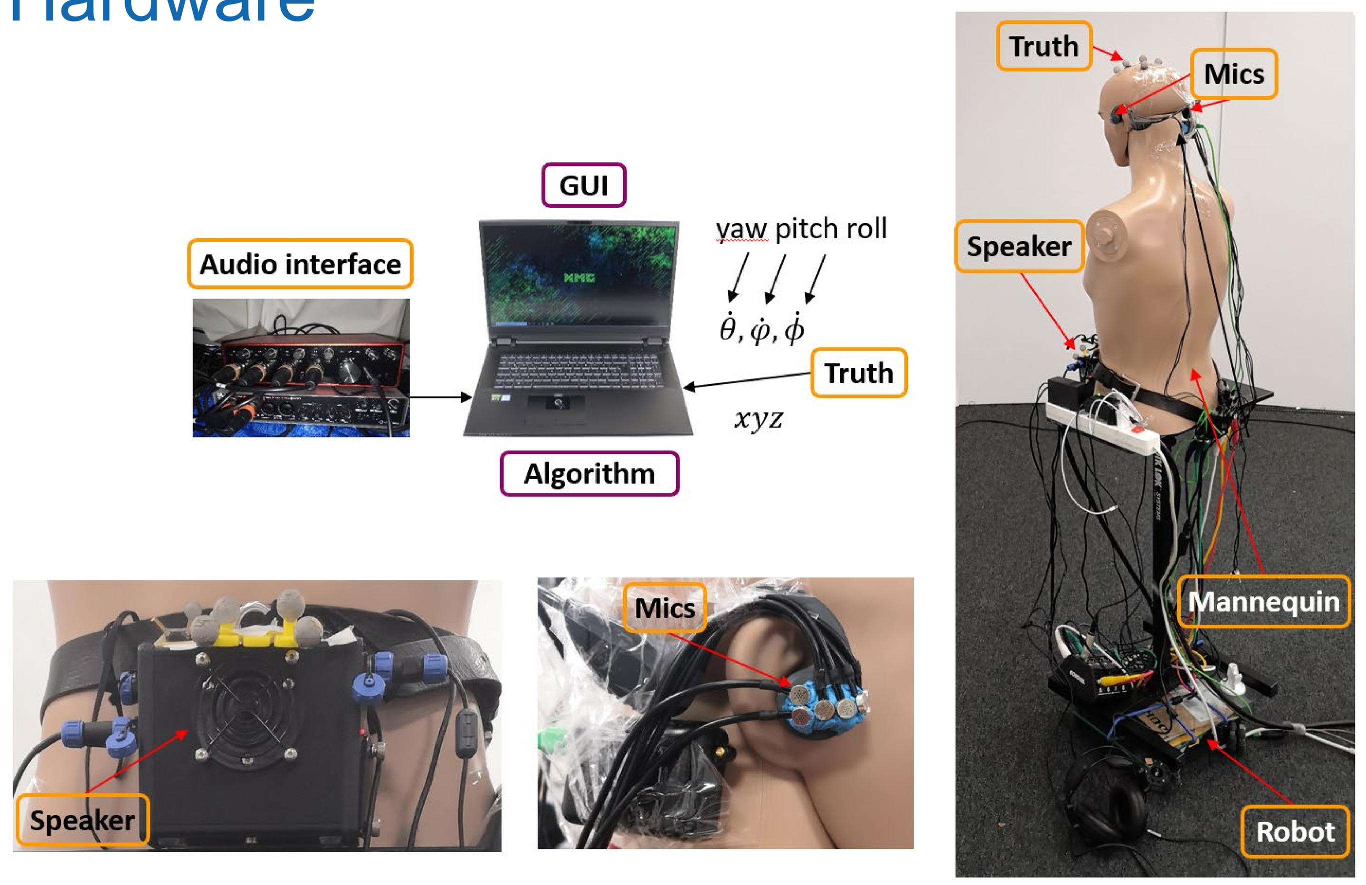
1. Reflection-based acoustic tracking



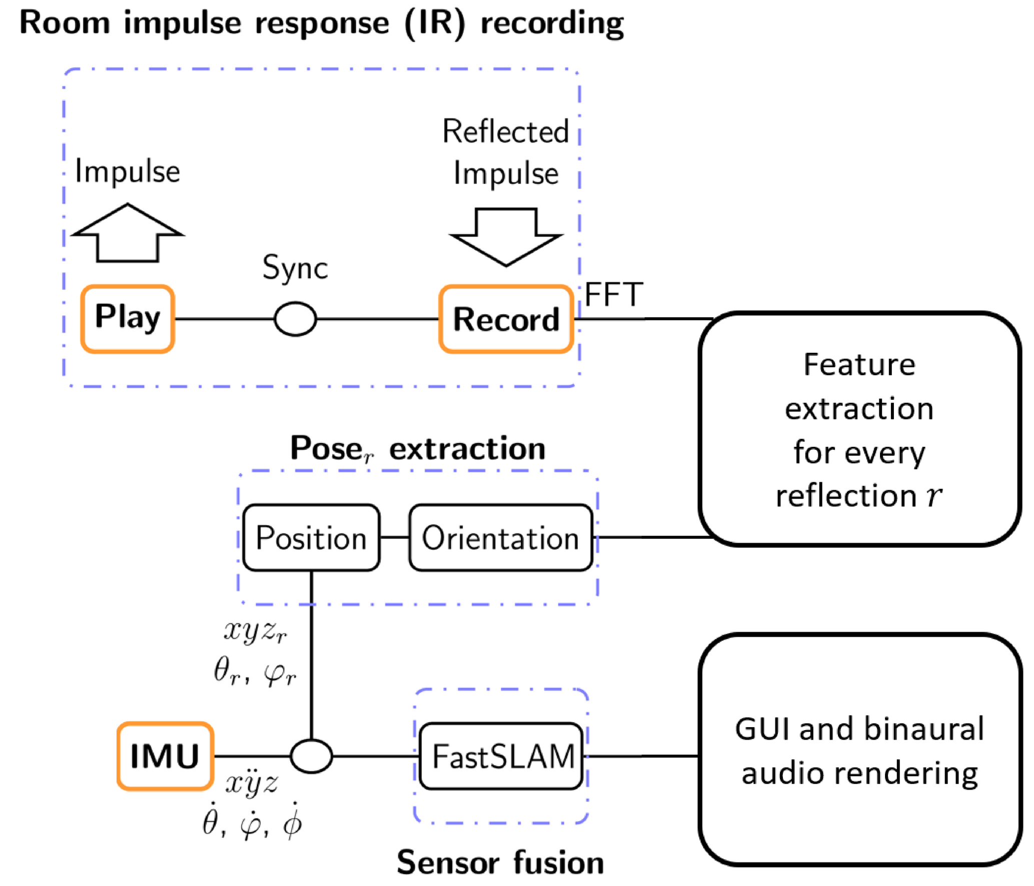
1. Monitor reflection: orientation ψ_1 and position xyz_1
2. Wall reflection: orientation ψ_2 and position xyz_2

Track Head Position via Headset Microphones

2. Hardware

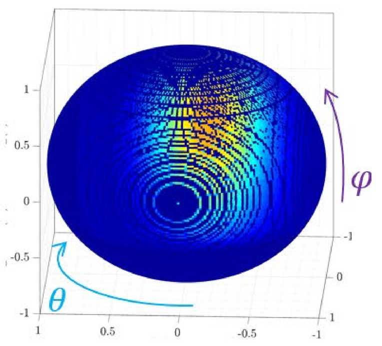


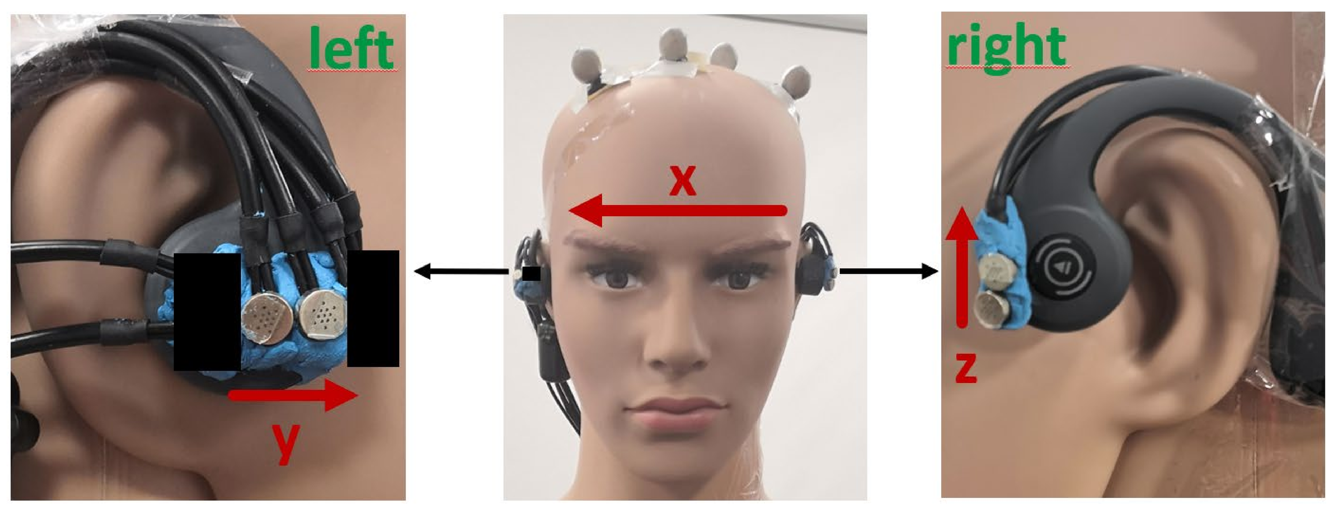
3. Reflection orientation estimation



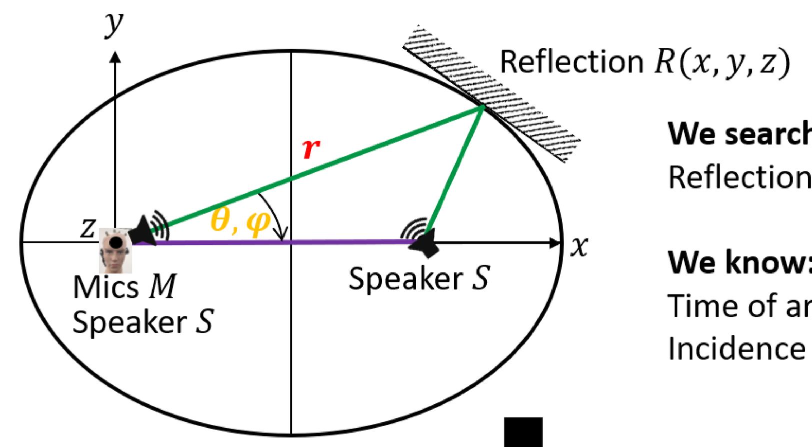
4. Method overview: tracking

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(α)
4. Map Cartesian propablity p(α) to spherical propablity p(θ, φ)





5. Method overview: mapping



We search:
Reflection distance r

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

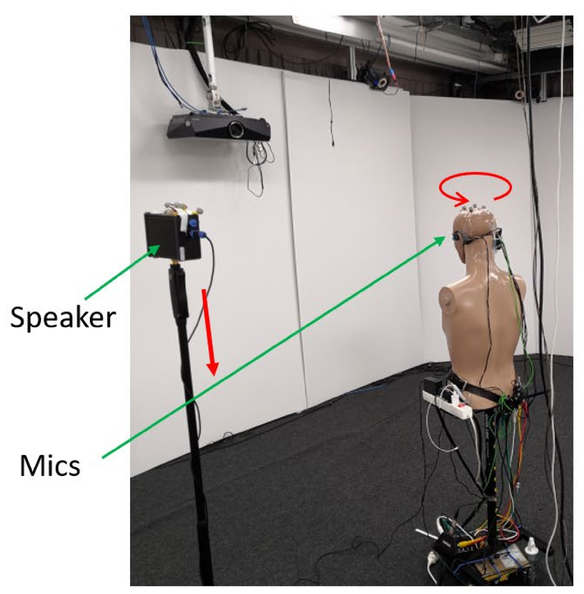
General solution:

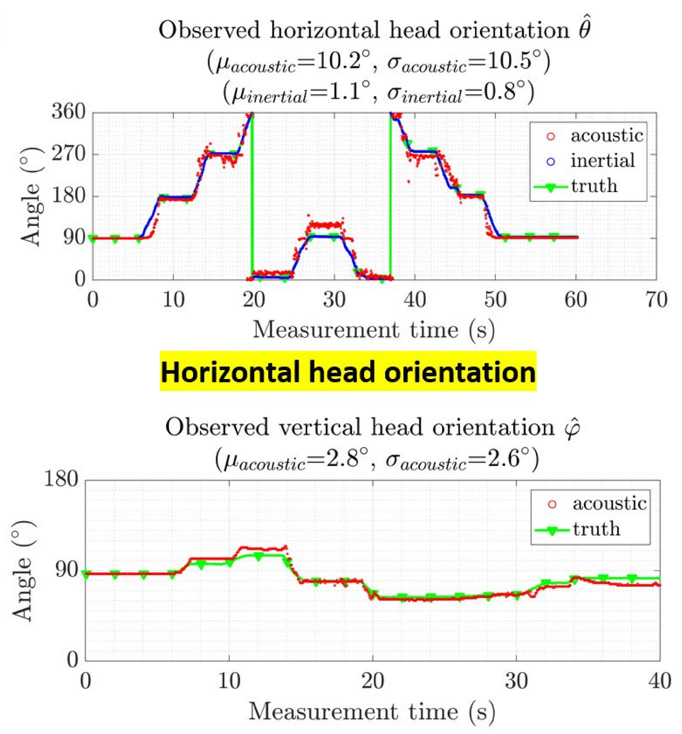
$$r = \frac{a\,(1-e^2)}{1+e\cdot\cos\theta\,\cos\varphi}\cdot SoS \text{ with semi-major axis } a = \frac{ToA_{SRM}}{2} \text{ and eccentricity } e = \frac{ToA_{SM}}{2a}$$

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

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

6. Experiments: tracking

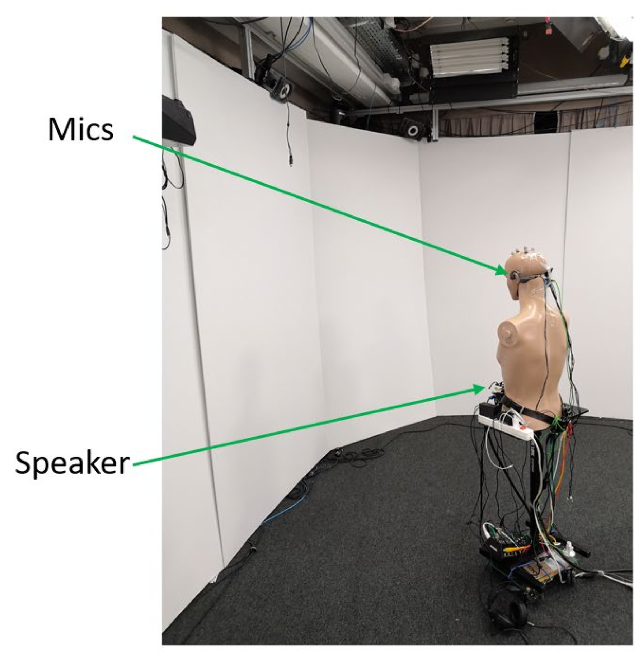


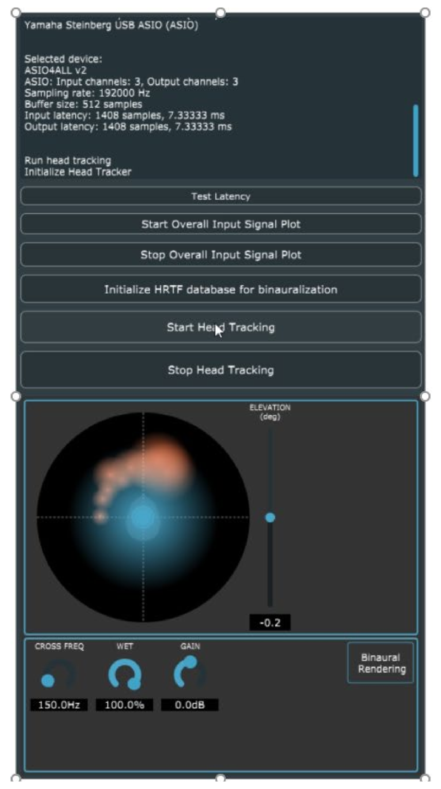


Horizontal head orientation

Vertical head orientation

7. Experiments: mapping





8. Conclusions

We formulate:
- Steps towards reflection-based acoustic 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: 30° (acoustic)
- Environment mapping

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

9. References

- A. Farina – Simultaneous Measurement of Impulse Response and Distortion with a Swept-Sine Technique, *In Proceedings of the 108th AES Convention, paper 5093, New York, 2000.*
- M. Montemerlo and S. Thrun – FastSLAM: A Scalable Method for the Simultaneous Localization and Mapping Problem in Robotics, *Springer Tracts in Advanced Robotics volume 27. Springer Verlag, 2007.*
- A. Kiruluta, M. Eizenman, and S. Pasupathy – Predictive Head Movement Tracking Using A Kalman Filter, *In IEEE Transactions on Systems, Man, and Cybernetics, 27(2):326-331, 1997.*
- J. D. Lawrence – A Catalog of Special Plane Curves, *Dover Publications, New York , 1972.*
- M. Krekovic, I. Dokmanic, and M. Vetterli – EchoSLAM: Simulatenous Localization and Mapping with Acoustic Echoes, *In 2016 IEEE International Conference on Acoustics, Speech and Signal Processing (ICASSP), 2016.*
- J. Blauert – The Technology of Binaural Listening, *Modern Acoustics and Signal Processing. Springer, 2013.*