Real-time spatial audio on the Internet of Things

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https://meteor.ame.asu.edu/projects/spatial-audio

Introduction

Spatially placed virtual sounds can create sounds in mid-air, or grant audio to objects that would otherwise be unable to produce sound, e.g., books, keys, utensils. Users could locate misplaced items through spatial audio guidance and/or allow users to interact with battery-less objects through auditory response.

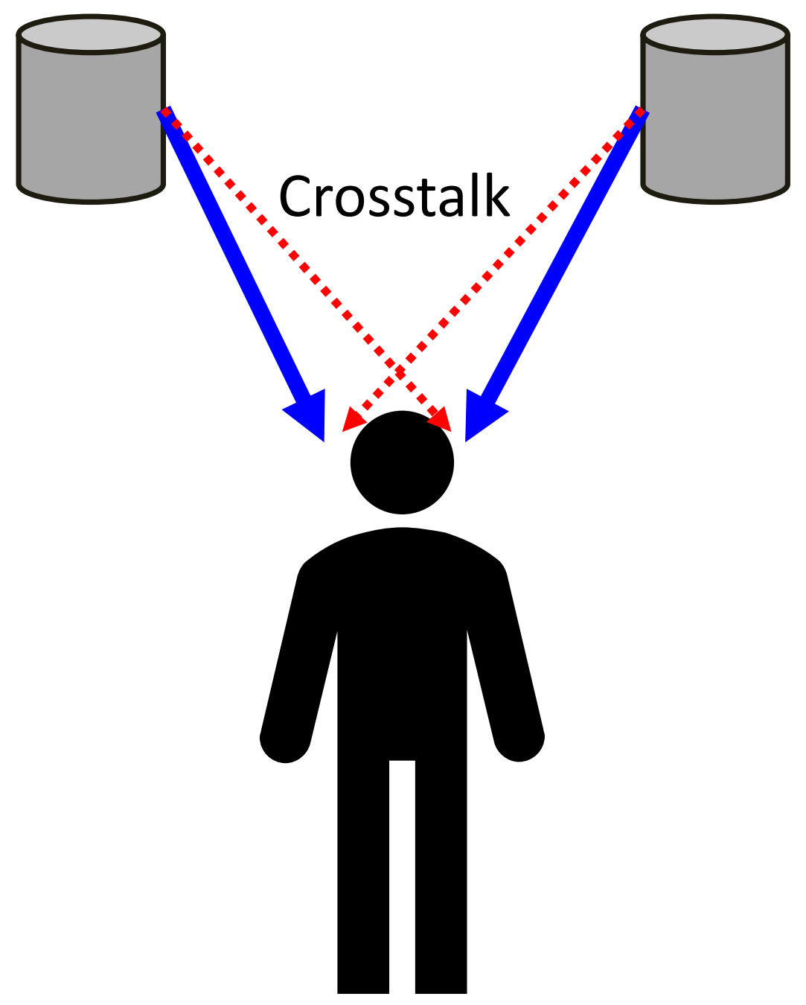
We've developed a prototype of the networked speakers on Internet-of-Things devices which can provide a fabric of spatial audio throughout homes, offices, and public spaces.

Challenge of Spatial Audio from Loudspeakers

Delivering spatial audio from loudspeakers is challenging due to crosstalk: the left sound signal

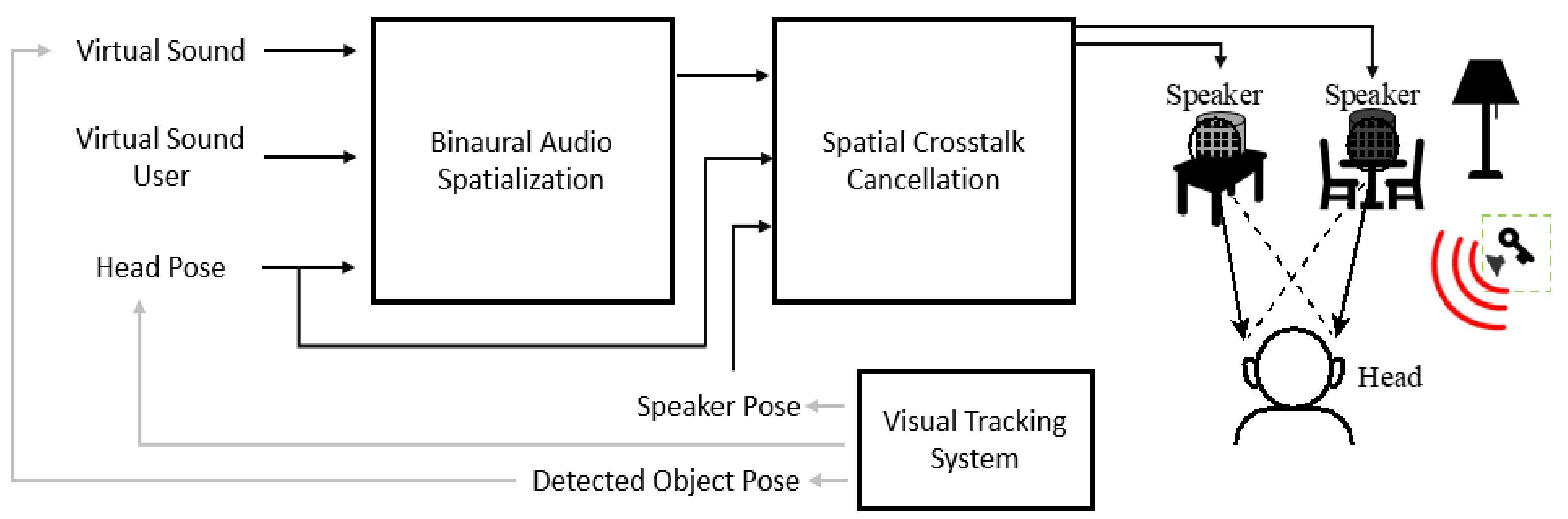
State-of-the-art crosstalk cancellation methods are expensive, requiring predesigned infrastructure and stationary observers.

- *Ambisonics* [1] and *amplitude panning* [2] require many surrounding speakers and require the user be in a specific fixed spot.
- *Dynamic crosstalk cancellers* for frequency domain audio processing have high latency and inaccuracy [3] or take significant calibration for the room and user transfer functions [4].



We propose a distributed spatial audio system that implements a time–domain dynamic crosstalk cancellation technique based on the geometry of a user's head position which uses estimations of amplitude decay and time delay to produce sound signals that become real-time binaural audio at the user's ears.

Geometrically-guided Spatial Audio Processing



Spatial Cross-talk Cancellation

Due to crosstalk, each ear receives a combination of decayed (α) and delayed (δ) signals from speakers S_1 and S_2 to form left and right ear signals $E_L(t)$ and $E_R(t)$.

$$\begin{aligned} E_L(t) &= \alpha_{1,L} S_1(t-\delta_{1,L}) + \alpha_{2,L} S_2(t-\delta_{2,L}) \\ E_R(t) &= \alpha_{1,R} S_1(t-\delta_{1,R}) + \alpha_{2,R} S_2(t-\delta_{2,R}) \end{aligned}$$

We use estimated α and δ information to create S_1 and S_2 signals that, when combined at the ear, will present left and right inputs $I_L(t)$ and $I_R(t)$ to the E_L and E_R respectively.

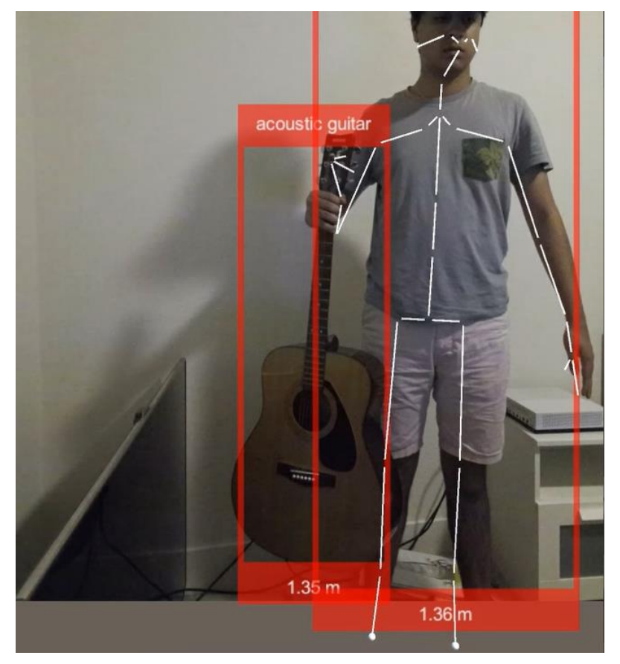
$$\begin{aligned} S_1(t) &= \frac{1}{\alpha_{1,L}} I_L(t-\Delta+\delta_{1,L}) - \frac{\alpha_{2,L}}{\alpha_{1,L}} S_2(t-\delta_{2,L}+\delta_{1,L}) \\ S_2(t) &= \frac{1}{\alpha_{2,R}} I_R(t-\Delta+\delta_{2,R}) - \frac{\alpha_{1,R}}{\alpha_{2,R}} S_1(t-\delta_{1,R}+\delta_{2,R}) \end{aligned}$$

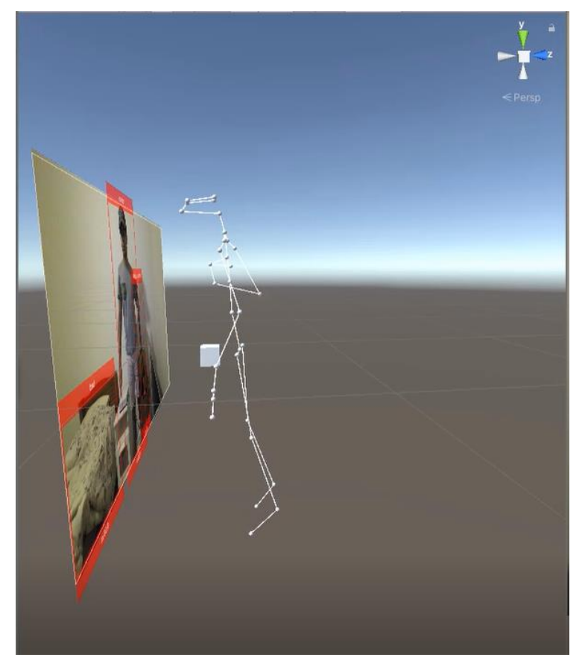
References

[1] D. Artega. 2018. Introduction to Ambisonics. Research Gate. https://www.researchgate.net/publication/280010078_Introduction_to_Ambisonics
[2] V. Pullki. 1997. Virtual sound source positioning using vector base amplitude panning. J. Audio Eng. Soc., vol. 45, pp. 456–466.
[3] H. Kurabayashi, M. Otani, K. Itoh, M. Hashimoto, M. Kayama. 2013. Development of dynamic transaural reproduction system using non-contact head tracking. In 2013 IEEE 2nd Global Conference on Consumer Electronics (GCCE), (Tokyo, Japan).
[4] M. Song, C. Zhang, D. Florencio, H. Kang. 2011. An Interactive 3-D Audio System with Loudspeakers. In IEEE Transactions on Multimedia (Volume: 13, Issue: 5, Oct. 2011)

Visual Tracking System

Kinect camera modules for body tracking and object detection. Physical Space is mapped to virtual space. Virtual sound source maps to center of bounding box of desired physical object.





Future Exploration

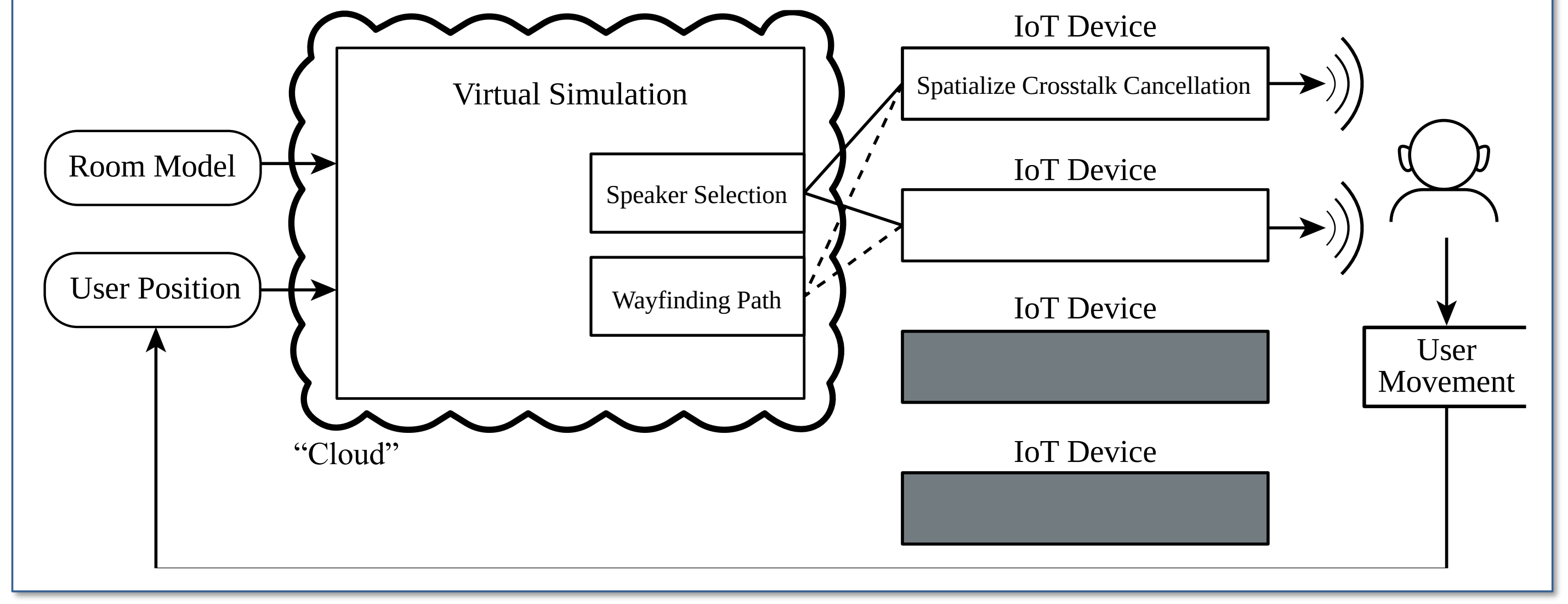
Calibration: Can we *retune system to work well in different environments?*

- Gathering and applying room /speaker sound models
- Real-time speaker selection for optimized binaural perception, including optimizing around predicted user movement (see below)

Sound Design : *What sounds spatialize best?*

- Understanding efficacy of natural and synthesized sound patterns
- Applying spatial motion patterns to spatial sounds for localization

Cloud-based room model simulation for speaker selection



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