Demo: Phase-based Acoustic Localization and Motion Tracking for Mobile Interaction

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ABSTRACT

Motion tracking, as a mechanism of mobile interaction, allows devices to get fine-gained user input by locating the real-time position of target devices (*e.g.*, smart phones, smart watches) in the air. With the proliferation of mobile devices and smart multimedia devices (*e.g.*, smart TV, home audio system), the ubiquitous speakers and microphones in the devices provide more diverse ways of acoustic-based mobile interaction. In this demonstration, we propose a fine-gained motion tracking system, which can be developed on commercial mobile devices and track the devices with millimeter level (mm-level) accuracy. We first compensate the phase offset between receiver and audio source at each frequency. We then use the acoustic phase change at receiver to achieve accurate distance measurement. Finally, we implement our system on off-the-shelf devices, and achieve a fine-gained motion tracking in two-dimensional space. Our experiments show that our system achieves high accuracy as well as high sensitivity: our system could detect the sight and slow movement caused by human breathing for example.

CCS CONCEPTS

• **Information systems** → **Mobile information processing systems**; • **Hardware** → Digital signal processing;

KEYWORDS

Acoustic Motion Tracking; Phase calibration; Mobile Interaction;

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1 INTRODUCTION

Motion tracking allows devices to get fine-grained user input by locating the real-time position of target devices (*e.g.*, smart phones, smart watches) in the air. Motion tracking is attractive in mobile social networks nowadays for supporting various applications, *e.g.*, mobile and video games, Virtual Reality (VR), Augmented Reality (AR), smart TVs. In recent years, many indoor localization and motion tracking methods on electromagnetic signals, such as Wi-Fi signal [3, 7], visible light [8, 9], millimeter wave [1, 4], have been proposed. The indoor localization methods provide promising means to achieve lightweight motion tracking in the future. However, most of them require customized hardware, which are costly at present which limit the availability to regular users. Further, the methods based on electromagnetic signals only have sub-meter level accuracy which is insufficient to track a user's gesture or posture. With the proliferation of mobile devices and smart multimedia devices, the ubiquitous speakers and microphones in the devices provide more diverse ways of acoustic phase-based mobile interaction[2, 5, 6]. Acoustic signal has its advantages in motion tracking, such as slow propagation velocity, the low sampling rate of acoustic signals.

In this demonstration, we propose a mobile devices (*e.g.*, smartphones) tracking scheme, called **P**hase-based Acoustic Localization and Motion **Track**ing (Ptrack) system, which can be developed on commercial mobile devices to provide fine-grained location and motion tracking for the devices. When senders transmit frames of inaudible acoustic sinusoidal signals at different frequency, the mobile device receives the signals. Then the receiver computes the distance from it to each sender, and estimate its location. Our key insight we can use the acoustic phase change at mobile devices to achieve accurate distance measurement. Ptrack first compensate the phase difference between audio sender and mobile devices. Then, We propose a novel method to evaluate the impact of multipath effects in different frequencies. We choose the signal with the impact with minimal impact to calculate the phase changes caused by the devices movement, and maps the phase changes into the distance of the movement. Finally, we implement our system on off-the-shelf devices, and achieve a fine-gained motion tracking.

2 OVERVIEW

The knowledge of audio signal's phase and frequency is a fundamental aspect for phase-based relative distance measurement. However, there are phase offsets between the smartphone and audio sources because the devices are independent. The offsets are different when the devices power up, which indicates that we can not accurately estimate the phase offset by prior knowledge. In order to make a compensation for the phase offsets, we propose a phase compensation algorithm which could compensate the phase offsets. The phase offsets are different at different frequencies. According to our experiments, the phase offsets at different frequencies can be seen as a linear increase in frequency domain for some time (*i.e.*, 15 minutes), In particular, we first measure the phase offsets at several frequencies, then we use a linear fit to estimate and compensate the phase offsets at other frequencies. The upshot of this is that each sender and receiver can be treated as synchronized over a period, despite being different devices.

We now give an overview of Ptrack when operating on a single sound frequency. We implemented our approach using different system sampling frequencies,*e.g.*, 44.1 KHz, 48 KHz, and has obtained similar results. Without loss of generality, we assume that the sampling frequency of the receiver is 48 KHz. In order to make the sound inaudible, the audio source of Ptrack operates sinusoidal signals, and the frequency of the signal is constant for each carrier and in the range of 17-23 KHz. The sound in the range can be generated and received by many commercial devices without introducing audible noises. We use the microphones on the smartphone to record the sound wave using the same sampling rate of 48 KHz. Because of the limited accuracy and resolution of existing

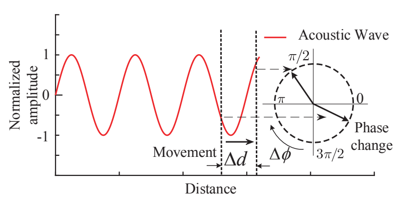
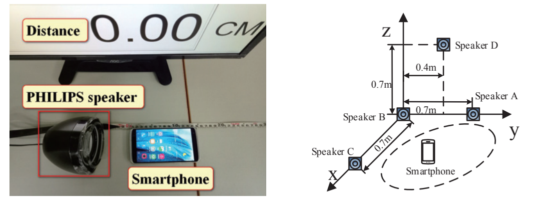


Figure 1: Active phase-based distance.

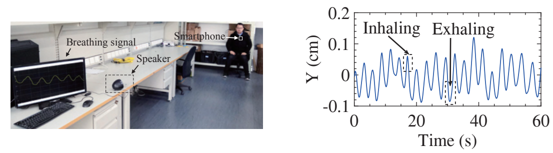
approaches, we propose a phase-based distance measurement approach for acoustic signals using direct-path signals. The change of the direct-path would cause phase change at receiver which could be accurately measured by Ptrack. According to the phase change $\Delta\phi$, we can calculate the distance change ΔD, as show in Fig.1.

We implement Ptrack on a platforms without any hardware modification. Our platform consists of a PC with Intel I7 CPU and 8 GB RAM used as a server. The PC has a sound card which could support multiple speakers. We use some PHILIPS PA311/93 speakers ($8 each) connected to the desktop, and the speakers transmit audio signals at different frequencies. We use the bottom microphone of smartphones to acquire the signal, and offload the computation of compensation and tracking to the server. The Experimental setup for 1-D and 2-D measurement as shown in Fig.2. Further, we use respiratory rate detection to evaluate Ptrack's ability of detecting remote micro movement, as shown in Fig.3.



(a) 1-D measurement **(b) 2-D and 3-D measurement**

Figure 2: Experimental Setup.



(a) Experimental setup **(b) Micro movement caused by human breathing**

Figure 3: Remote micro movement detection.

3 DEMONSTRATION

In this demonstration, we will show real-time Ptrack system and its efficacy to enable fine-grained localization and tracking with high sensitivity using acoustic signals. We will bring commercial speakers, smartphones, and laptops for the demonstration. In this system, we will demonstrate real-time fine-grained 1-D distance measurement between a speaker and a smartphone, detect small and slow movement caused by human breathing rate at different distance, run real-time motion tracking in two-dimensional space under noisy indoor environments. During the demonstration, we will need a power outlet for the devices, and also need a desk with around $1m \times 2m$ space to place the equipments. The whole setup process could been completed less than an hour.

4 CONCLUSIONS

By leveraging existing multimedia devices, Ptrack provides fine-grained real-time localization and motion tracking using inaudible acoustic signals. The system could be implemented on commercial devices, such as smartphone, tablets, laptop, and desktop without any hardware modification. Ptrack introduces a novel phase compensation algorithm to achieve acoustic phase synchronization at each frequency between devices over a period. It further designs a multi-path effect mitigation algorithm to improve the performance under dynamic indoor environments. We believe this work will make a strong push towards novel acoustic-based applications using ubiquitous multimedia devices.

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