

# hEARt: Motion-resilient Heart Rate Monitoring with In-ear Microphones

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Heart rate is a key physiological marker of cardiovascular health and physical fitness. Monitoring heart rate during exercise is critical as it allows the meeting of cardiac goals and maximises training effort. Continuous and reliable HR monitoring with wearable devices has therefore gained increasing attention in recent years. However, existing heart rate detection systems in wearables mainly rely on photoplethysmography (PPG) sensors, which are notorious for poor performance in the presence of human motion. With the increasing adoption of in-ear wearables in everyday life, the research community has started investigating suitable in-ear heart rate detection systems.

In this work, we leverage the occlusion effect that enhances low-frequency bone-conducted sounds in the ear canal. Using this, we investigate, for the first time, *in-ear audio-based motion-resilient* HR monitoring. We present an analysis of the interference imposed by common human activities on in-ear heart sounds, where we show that human activities corrupt the heart sounds, making it difficult to denoise the signals in either the frequency or time domain. Using this analysis, we present a system for HR monitoring using in-ear audio under motion conditions.

To achieve this, we first collected heart rate-induced sounds in the ear canal using an in-ear microphone. We collected data while subjects were stationary and undergoing three different activities: walking, running, and speaking. We developed a custom earable platform containing microphones facing inside the ear canal which were embedded into commercial earbuds, and sampled by a Raspberry Pi. Using this platform, we collected data from 20 subjects, using an ECG chest strap as ground truth.

To denoise the in-ear audio signals and determine heart rate under motion conditions, we devised a novel deep-learning based motion artefact mitigation framework. The framework uses the U-Net architecture to map spectrograms of the noisy heart sounds to their corresponding ECG signals, thus producing an output synthesised ECG signal. Due to the limited size of our dataset, we also leverage transfer learning to pretrain the model using a large dataset of heart sounds. We use spectrograms of the heart sounds as input and label to the network to teach the network to effectively capture heart sound related information. From the resultant synthesised ECG signals, we use a heart rate estimation algorithm based on peak detection to extract the heart rate.

We demonstrate that our end-to-end approach, hEARt, achieves a mean absolute error of  $3.02 \pm 2.97$  BPM,  $8.12 \pm 6.74$  BPM,  $11.23 \pm 9.20$  BPM and  $9.39 \pm 6.97$  BPM for stationary, walking, running and speaking, respectively. Not only does hEARt outperform previous in-ear HR monitoring work [1], but it also outperforms reported in-ear PPG performance [2]. We also assess performance on an individual basis and show that hEARt generalises well to different activities and is able to track heart rate over time. This work opens the door to a new avenue of non-invasive and affordable HR monitoring with usable performance for daily activities.

## REFERENCES

- [1] A. Martin and J. Voix, "In-ear audio wearable: Measurement of heart and breathing rates for health and safety monitoring," *IEEE Transactions on Biomedical Engineering*, vol. 65, no. 6, pp. 1256–1263, 2017.
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