Demo Abstract: eSense - Open Earable Platform for Human Sensing

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ABSTRACT

We present eSense - an open and multi-sensory in-ear wearable platform for personal-scale behaviour analytics. eSense is a true wireless stereo (TWS) earbud and supports dual-mode Bluetooth and Bluetooth Low Energy. It is also augmented with a 6-axis inertial measurement unit and a microphone. We demonstrate the eSense platform, the data exploration tool with the open APIs for the real-time visualisation of multi-modal sensory data, and its manifestation in a 360° workplace well-being application.

CCS CONCEPTS

• **Human-centered computing → Ubiquitous and mobile computing systems and tools**;

KEYWORDS

Earable, human sensing, behaviour analysis

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1 INTRODUCTION

Wearables are finally here. Established forms, e.g., a timepiece, a ring, and a pendant are getting a digital makeover and are reshaping our everyday experiences with new, useful, exciting and sometimes entertaining services. However, for a broader impact on our lives, the next generation wearables must expand their sensing capabilities beyond the narrow set of exercise-related physical activities.

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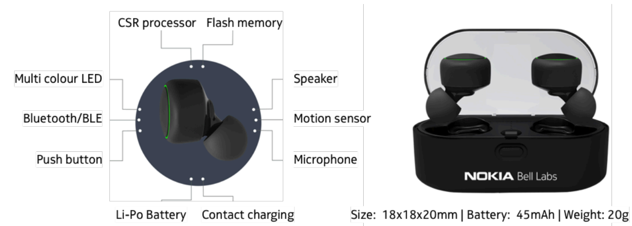

Figure 1: eSense open wearable platform.

To this end, we present eSense - an aesthetically pleasing, and ergonomically comfortable in-ear high definition wireless stereo wearable [1]. As illustrated in Figure 1, eSense is equipped with a microphone, a 6-axis inertial measurement unit, and a dual-mode Bluetooth and Bluetooth Low Energy (BLE). Leveraging the combination of microphone, accelerometer, gyroscope, and BLE, eSense offers three sensing modalities - audio, motion, and proximity. It is powered by a CSR processor and a 45 mAh battery. Most importantly, eSense is an entirely open data platform that allows developers to gather real-time data streams of these multi-sensory modalities as well as offering them with several configurations and reprogramming capabilities.

Earables provide unique opportunities and advantages for human sensing. First, placement in the ear enables earables to monitor head and mouth movements besides whole-body movements in a non-invasive way. This unique capability uncovers opportunity for many novel applications in the areas of personal health, dietary monitoring, and attention management. Second, earables are intimate and discreet enabling users to have immediate and hands-free access to information in a privacy-preserving and socially acceptable way. Third, earables provide the freedom of movement and hands-free interaction minimising situational disability and fragmentation of attention. Besides, earables can be worn for long hours without any impact on primary motor and cognitive activities.

2 EARABLE SENSING

We have extensively explored the characteristics of audio, inertial, and BLE signals captured by eSense in a variety of experimental settings. We compared eSense against a smartphone and a smartwatch considering several key factors that impact activity recognition pipelines, including sampling variability, signal to noise ratio, placement invariance, and sensitivity to motion artefacts. Analysis of our experimental results suggests that eSense is robust in modelling these signals and in most conditions demonstrates superior performance concerning signal stability and noise sensitivities. Inspired by these characteristics, we have designed a set of human activity primitives. Bespoke classifiers are then trained to model these activities with audio, motion, and BLE signals, and their combinations. The experimental results demonstrate that eSense can reach up to 88% detection accuracy for the targeted human activities [1, 4].

We further explored the earable sensing on ambitious applications such as dietary monitoring [3] and conversational well-being monitoring [5]. First, earable are ideal for dietary monitoring by virtue of their placement. They are worn close to a user's mouth, jaw, and throat which make them capable of capturing any acoustic events originating in these body parts. Inertial sensors can potentially capture movements of the head and jaw that are often associated with food intake. As such, by fusing audio and inertial sensing signals, we have designed an audio-kinetic model for automatic dietary monitoring [3]. The results show that our model achieves higher accuracies for the chewing and drinking activities.

Second, we studied conversation well-being monitoring [5]. Capturing sophisticated social, emotional contexts from conversations has been actively studied in mobile computing, but most work relies on the microphone on smartphones. However, this has two practical limitations. These devices have low reliability to monitor conversational interaction, owing to their placement, e.g, the smartphones in a pocket or bag, and hence the quality of the recorded speech signal may be poor in some situations. Also, they require the continuous audio recording during a conversation, which is energy-heavy and privacy-invasive. To enable the qualification of conversation well-being on earables, We developed a *cross-modal* approach for conversational well-being monitoring. It consists of three sensing models, BLE, motion, and audio models, each of which detects a conversation group, speaking activities, and stress and emotion using BLE advertisements, the IMU sensor, and the microphone, respectively. Our approach saves energy significantly by avoiding continuous audio processing. Also, more importantly, it enables the speaker-specific quantification of emotion and stress as the motion model can identify a speaker accurately, i.e., who is speaking and who is not during face-to-face conversation.

Taken together these and the rest of our findings demonstrate the exciting potential of eSense as an in-ear wearable sensing platform for designing individual scale multi-sensory applications.

3 DEMONSTRATION

We will demonstrate eSense, an open earable platform showcasing three aspects of the system.

eSense hardware: We will show our hardware prototypes so that the attendees can freely wear and experience the devices. Attendees will be able to use the devices as common in-ear headphones, for example listening to music.

Sensing capability of eSense: We will show the sensing capability of eSense with a real-time visualisation tool as illustrated in Figure 2. The four sensor streams (accelerometer data, gyroscope

Figure 2: eSense data exploration tool.

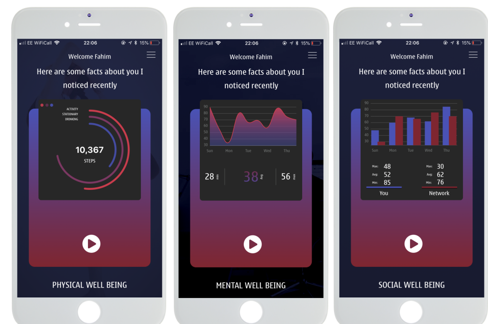

Figure 3: 360° workspace well-being app.

data, BLE RSSI, and microphone data) will be shown, simultaneously and in real time on a web-based tool. Attendees will be able to interact with the devices and see immediately how their interaction affects the displayed signals.

Potential use of eSense: To show a potential use of eSense, we will demonstrate a quantified enterprise smartphone application as depicted in Figure 3. Using eSense as a data collection platform, the application shows a variety of well being attributes in an enterprise context. In particular, three aspects of well being are considered: physical, mental and social well being. The application models eSense sensory streams for a variety of physical, digital, and social well-being metrics [2]. The metrics are displayed in a simple and immediately understandable interface together with personalised and conversational feedback.

REFERENCES

[1] Fahim Kawsar, Chulhong Min, Akhil Mathur, and Alessandro Montanari. 2018. Earables for Personal-scale Behaviour Analytics. *IEEE Pervasive Computing* 17, 3 (2018).

[2] Afra Mashhadi, Akhil Mathur, Marc Van den Broeck, Geert Vanderhulst, and Fahim Kawsar. 2016. Understanding the impact of personal feedback on face-to-face interactions in the workplace. In *Proceedings of the 18th ACM International Conference on Multimodal Interaction (ICMI '16)*. ACM, 362–369.

[3] Chulhong Min, Akhil Mathur, and Fahim Kawsar. 2018. Audio-Kinetic Model for Automatic Dietary Monitoring with Earable Devices. In *Proceedings of the 16th Annual International Conference on Mobile Systems, Applications, and Services (MobiSys '18)*. ACM, New York, NY, USA, 517–517.

[4] Chulhong Min, Akhil Mathur, and Fahim Kawsar. 2018. Exploring Audio and Kinetic Sensing on Earable Devices. In *Proceedings of the 4th ACM Workshop on Wearable Systems and Applications (WearSys '18)*. ACM, New York, NY, USA, 5–10.

[5] Chulhong Min, Alessandro Montanari, Akhil Mathur, Seungchul Lee, and Fahim Kawsar. 2018. Cross-Modal Approach for Conversational Well-being Monitoring with Multi-Sensory Earables. In *Proceedings of the First International Workshop on Computing for Well-being (WellComp '18)*. ACM.