OpenEarable Suite: Open-Source Hardware to Sense 30+ Phenomena on the Ears

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Figure 1: (A) OpenEarable, an in-ear sensing earable with a PPG, optical temperature, pressure, and IMU sensor as well as 2 ultrasound capable microphones; (B) OpenEarable ExG, a platform for sensing in-ear-based biopotentials; (C) Open ExG Headphones to measure biopotentials around the ears based on OpenBCI [7].

Abstract

In this demo, we showcase the OpenEarable Suite, a comprehensive collection of ear-worn devices designed to sense and analyze over 30 different phenomena. The collection includes three distinct devices: OpenEarable, OpenEarable ExG, and Open ExG Headphones. "OpenEarable" integrates advanced sensors, such as ultrasound-capable microphones, a 9-axis inertial measurement unit, a pulse oximeter, an optical temperature sensor, and an ear canal pressure sensor, enabling extensive health monitoring, activity tracking, and human-computer interaction. "OpenEarable ExG" is an open-source platform focused on measuring biopotentials like EEG, ECG, and EMG, using up to four sensing channels, and is validated for detecting eye movements, brain activity, and muscle contractions. "Open ExG Headphones" combine electrophysiological sensing with high-quality audio, utilizing OpenBCI biosignal amplification and a 3D-printed over-ear design for reliable EEG, EOG, ECG, and EMG measurements. The OpenEarable Suite aims to democratize earable research by providing accessible, open-source tools in different form factors that follow best practices in hardware and software development, facilitating diverse applications across various domains from medical to HCI.

CCS Concepts

• **Hardware → Emerging technologies**; • **Human-centered computing → Ubiquitous and mobile computing systems and tools**; **Ubiquitous and mobile devices**;

Keywords

earables; hearables; open-source hardware; OSHW; open wearables

1 Introduction

The evolution of earphones from simple audio devices to multifunctional "earables" has opened new avenues for sensing and analyzing a wide range of physiological and environmental phenomena [9]. Earables, worn in or around the ear, are uniquely positioned to capture diverse biosignals due to their proximity to critical anatomical sites, such as the brain, eyes, and major arteries. This advantageous placement positions earables as an exciting platform for physiological tracking [12], health applications [2], activity tracking [4], interaction [10], and authentication as well as identification [3]. Despite the promising capabilities of earables, the development of

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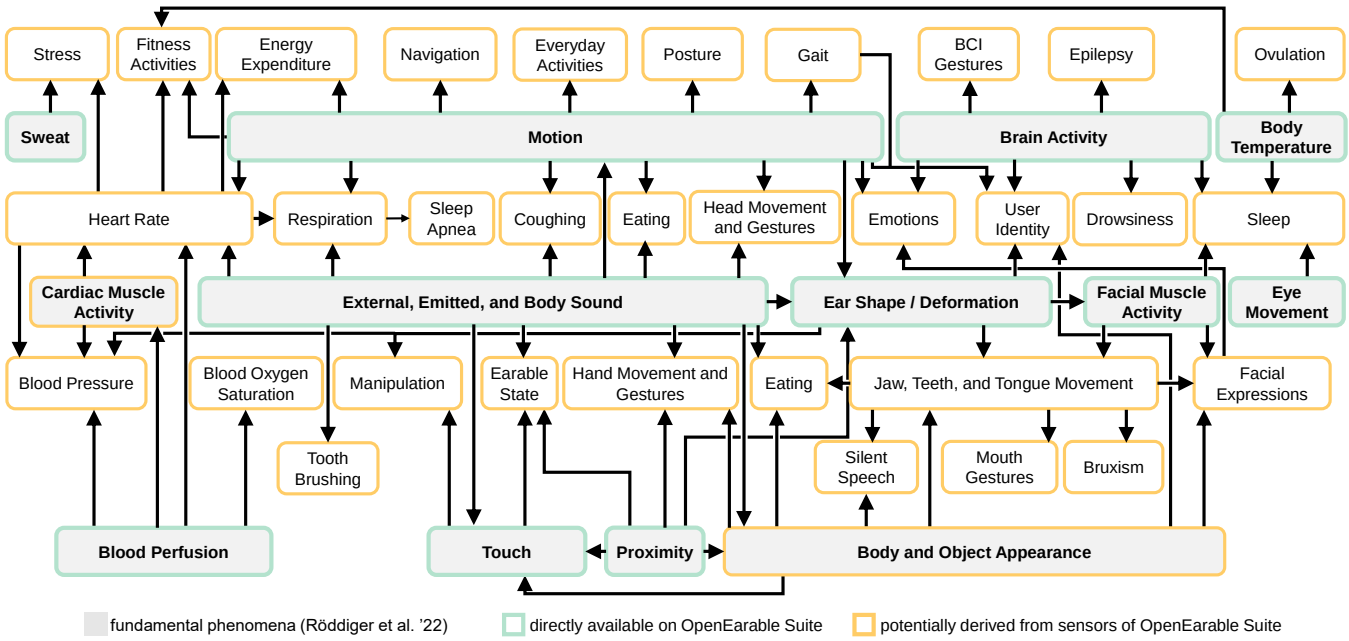

Figure 2: Using the sensors in the different OpenEarable devices, it is possible to sense over 30 phenomena in and around the ears [9]. This shows how earables are arguably one of the most versatile wearable platforms.

bespoke research devices has been challenging due to their complexity and the expertise required for their creation.

To address this problem, researchers at the Karlsruhe Institute of Technology in Germany have developed a series of open-source platforms for sensing phenomena in and around the ears. The OpenEarable Suite consists of three distinct devices (see Figure 1): OpenEarable, OpenEarable ExG, and Open ExG Headphones. Each device is designed to provide robust and reliable data collection across various domains and in different form factors. The devices are developed open-source for anyone to rebuild. Our demo will give anyone attending the opportunity to try out the OpenEarable devices first-hand and understand how the different platforms can contribute to different research needs. A summary of the diverse phenomena that can be measured with and derived from the OpenEarable Suite worn in and around the ears is shown in Figure 2.

2 OpenEarable

OpenEarable functions as regular binaural Bluetooth in-ear earphones while providing sensing capabilities [11]. It follows best practices from the open hardware community [1]. The platform's firmware and hardware are fully open-source, implemented using freely available tools and frameworks to promote collaboration within the research community. Each earpiece is equipped with a suite of sensors designed to monitor and measure a variety of phenomena, including two ultrasound-capable microphones (inward/outward) for capturing internal and external acoustic sounds, a 9-axis inertial measurement unit (IMU) for movements and orientation, a pulse oximeter for measuring blood oxygen levels and heart rate, an optical temperature sensor for measuring concha temperature, an ear canal pressure sensor for detecting changes in ear canal shape, and a microSD card for data storage. OpenEarable includes a web-based dashboard and a mobile smartphone app, providing an interface for managing the device, visualizing data, and configuring sensor settings. The wearability and sensing capabilities of OpenEarable have been validated through different studies, to demonstrate its accuracy and reliability compared to established gold-standard measurements. OpenEarable is available fully open-source under MIT license.[1] During the demo, participants will have the opportunity to wear the OpenEarable to measure diverse phenomena. In addition, they can try different earable apps that make use of the sensors, for example a head pose tracker or a rope-skipping counter. This should inspire participants of this demo to pursue their own research with OpenEarable.

3 OpenEarable ExG

OpenEarable ExG is an open-source hardware platform designed to measure biopotentials in and around the ears. It is based on OpenEarable 1.3 [11]. OpenEarable ExG is freely configurable and features up to seven sensing channels. OpenEarable ExG has been validated in a study using a left-right in-ear dual-electrode montage setup with three participants, successfully detecting smooth pursuit eye movements via Electrooculography (EOG), alpha brain activity via Electroencephalography (EEG), and jaw clenching via Electromyography (EMG). The earpieces are custom-made with 3D-printed enclosures and Dätwyler SoftPulse in-ear electrodes, ensuring comfort and ease of use. As part of the OpenEarable initiative, OpenEarable ExG is fully open-source under the MIT license.[2] During the demo, participants will have the opportunity to wear

[1] https://github.com/OpenEarable/open-earable
[2] https://github.com/OpenEarable/open-earable-ExG

the OpenEarable ExG to measure their brain, eyes, and muscle activities. This should inspire participants of this demo to pursue their own research with OpenEarable ExG.

4 Open ExG Headphones

The Open ExG Headphones are an integration of the popular OpenBCI Cyton, Daisy, and Ganglion amplifiers [7], designed to provide a highly accessible and advanced solution for electrophysiological measurements [6]. In this around-the-ear ExG recording system, the OpenBCI platform provides the amplifiers and the software stack necessary for high-quality data collection - a solution that has already been used for related modifications [5, 6]. The system uses custom-built flex-PCBs that connect the amplifier in one ear to the electrodes safely and efficiently. Flex-PCBs with gold-plated pads on the cushions serve as electrodes, and spring-loaded, gold-plated pins inserted in the headband cushion offer additional channels on top of the head. Altogether the system can be flexibly configured for either 4-, 8-, or 16-channel recordings depending on the use of a Ganglion, Cyton, or Cyton+Daisy amplifier. The associated software stack, including a GUI (OpenBCI GUI) and APIs (e.g. Brainflow), simplify the recording process and application development. The Open ExG Headphones have been evaluated for different applications, including heartbeat and facial muscle activity detection, eye tracking, and oscillatory neural phenomena like cognitive load or visual input processing [6, 8]. As part of the OpenEarable initiative, the Open ExG Headphones are fully open-source.[3] During the demo, participants will have the opportunity to wear the Open ExG Headphones to measure their brain, eyes, and muscle activities. This should inspire participants of this demo to pursue their own research with Open ExG Headphones.

5 Conclusion

In this demo, participants have the opportunity to experience the different OpenEarable platforms first-hand. This way, they can learn more about the diverse application opportunities of earables for sensing a large variety of phenomena in and around the ears ranging from health applications and activity tracking to human-computer-interaction and even authentication. We invite the community to join our efforts in open wearable computing and contribute to our growing suite of devices for different locations across the body.

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References

[1] Open Source Hardware Association. 2024. Open Source Hardware Association (OSHWA). https://www.oshwa.org/. Accessed: 2024-07-09.

[2] Kayla-Jade Butkow, Ting Dang, Andrea Ferlini, Dong Ma, and Cecilia Mascolo. 2023. heart: Motion-resilient heart rate monitoring with in-ear microphones. In *2023 IEEE International Conference on Pervasive Computing and Communications (PerCom)*. IEEE, 200–209.

[3] Andrea Ferlini, Dong Ma, Robert Harle, and Cecilia Mascolo. 2021. EarGate: gait-based user identification with in-ear microphones. In *Proceedings of the 27th Annual International Conference on Mobile Computing and Networking*. 337–349.

[4] Fahim Kawsar, Chulhong Min, Akhil Mathur, and Alessandro Montanari. 2018. Earables for personal-scale behavior analytics. *IEEE Pervasive Computing* 17, 3 (2018), 83–89.

[5] Michael Thomas Knierim, Christoph Berger, and Pierluigi Reali. 2021. Open-source concealed EEG data collection for Brain-computer-interfaces-neural observation through OpenBCI amplifiers with around-the-ear cEEGrid electrodes. *Brain-Computer Interfaces* 8, 4 (2021), 161–179.

[6] Michael Thomas Knierim, Daniel Puhl, Gabriel Ivucic, and Tobias Röddiger. 2023. OpenBCI+ 3D-Printed Headphones= Open ExG Headphones–An Open-Source Research Platform for Biopotential Earable Applications. In *Extended Abstracts of the 2023 CHI Conference on Human Factors in Computing Systems*. 1–7.

[7] OpenBCI. 2024. OpenBCI | Home. https://openbci.com/. (Accessed on 07/09/2024).

[8] Tobias Röddiger. 2023. *Earables: Wearable Computing on the Ears*. Ph. D. Dissertation. Karlsruhe, Karlsruher Institut für Technologie (KIT).

[9] Tobias Röddiger, Christopher Clarke, Paula Breitling, Tim Schneegans, Haibin Zhao, Hans Gellersen, and Michael Beigl. 2022. Sensing with earables: A systematic literature review and taxonomy of phenomena. *Proceedings of the ACM on interactive, mobile, wearable and ubiquitous technologies* 6, 3 (2022), 1–57.

[10] Tobias Röddiger, Christopher Clarke, Daniel Wolffram, Matthias Budde, and Michael Beigl. 2021. EarRumble: discreet hands-and eyes-free input by voluntary tensor tympani muscle contraction. In *Proceedings of the 2021 CHI Conference on Human Factors in Computing Systems*. 1–14.

[11] Tobias Röddiger, Tobias King, Dylan Ray Roodt, Christopher Clarke, and Michael Beigl. 2022. Openearable: Open hardware earable sensing platform. In *Adjunct Proceedings of the 2022 ACM International Joint Conference on Pervasive and Ubiquitous Computing and the 2022 ACM International Symposium on Wearable Computers*. 246–251.

[12] Tobias Röddiger, Daniel Wolffram, David Laubenstein, Matthias Budde, and Michael Beigl. 2019. Towards respiration rate monitoring using an in-ear headphone inertial measurement unit. In *Proceedings of the 1st International Workshop on Earable Computing*. 48–53.

[3] https://github.com/MKnierim/openbci-headphones