Demo: Earable - An Ear-Worn Biosignal Sensing Platform for Cognitive State Monitoring and Human-Computer Interaction

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ABSTRACT

Cognitive state monitoring is crucial for neurological disorders such as epilepsy, narcolepsy, insomnia, and many other human health concerns. The capability to continuously monitor an individual wearing the device and accurately provide early warnings of seizures or narcolepsy sleep attacks would be game-changing for these disorders. Beyond human health, complete hand-free/voice-free human-computer interaction is desirable for privacy-sensitive use cases or people with disabilities. To achieve this goal, we propose Earable, an ear-worn biosensing platform for cognitive state quantification and human-computer interaction. Earable can capture biosignal including brain waves activities, eyes movements, and facial muscle contractions from the back of the ears. Its form factor is convenient to use in everyday life. In this demo, we show two use cases for our Earable platform. First, as an example of cognitive state monitoring, our system plays relaxing music and dims the light when the user is trying to relax or sleep by detecting alpha and beta waves generated by the brain. Second, as an example of human-computer interaction, our system controls a drone with eye movements and facial muscle activity.

CCS CONCEPTS

• Human-centered computing → Ubiquitous and mobile computing systems and tools; **• Computer systems organization → Embedded and cyber-physical systems**.

1 INTRODUCTION

Continuous cognitive state monitoring and human-computer interaction are two important applications of future wearable devices. The number of people who suffer from neurological disorders including epilepsy, narcolepsy, or insomnia is increasing and many are still uncured [6–8]. Due to this trend, cognitive monitoring is increasingly important for human health. The capability for continuous and accurate monitoring and ability to provide early warnings of seizures or narcolepsy sleep attacks is one of Earable's core value propositions. Additionally, complete hand-free/voice-free human-computer interaction is another application that is desirable for privacy-sensitive use cases or people with disabilities.

For those suffering from health conditions like Epilepsy and Narcolepsy, a sudden and unpredictable seizure, or sleep attack can be life-threatening. One-third of Epilepsy patients and all Narcolepsy patients are uncured, a combined global population of nearly 20 million individuals [3, 9]. 58% of this group is unemployed [4, 5] causing a roughly $200 billion reduction in global GDP [1, 2, 12]. Without an unobtrusive, low-cost, and real-time biosensing platform to quantify and help their conditions daily, these patients represent a massive, unaddressed human tragedy.

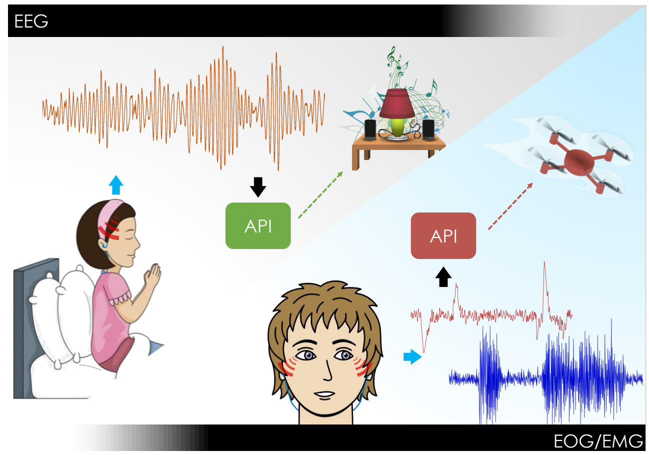

Figure 1: Cognitive state monitoring and human-computer interactions with Earable.

Earable offers an advanced, ear-worn biosensing platform for cognitive state quantification and human-computer interaction. Earable can detect biosignal that includes brain activities, eye movements, and muscle contractions from electroencephalography (EEG), electrooculography (EOG), and electromyography (EMG), respectively. The back of the ear is the optimal position to obtain these signals because it is socially acceptable and close to temporal lobes, eyes balls, and facial muscles [10, 11]. Each biosignal shows a characteristic change according to the physical condition and movement. By interpreting these signals, we can connect a person's physiological state or intention to the related services.

Unlike any previous devices in literature or on the market, Earable's compact and wearable form factor combined with accurate biosignal recognition software enables daily monitoring of one's cognitive state, and real-time action to address an upcoming incident. Furthermore, Earable enables a new method for hands-free, conscious and automatic control over IoT devices which are often otherwise controlled manually. Many new, beneficial technologies and life-changing, treatment options can be seamlessly integrated into users' daily lives through this platform, with significant societal impact.

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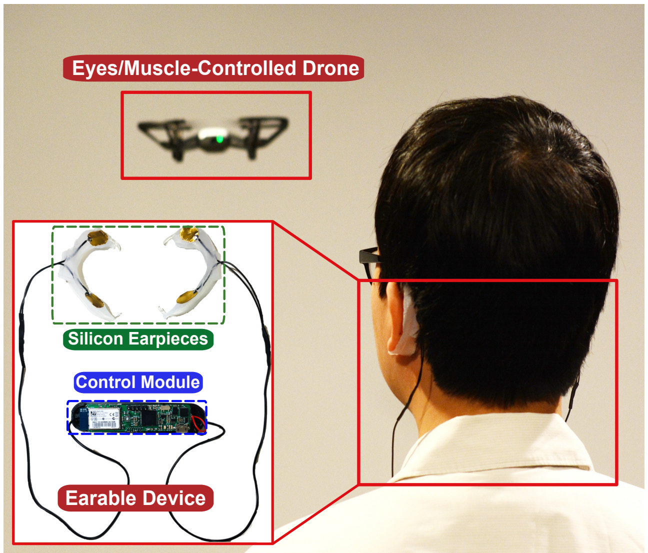

Figure 2: Hand-free drone control with eyes movements and facial muscle activity captured by our Earable prototype.

2 EARABLE PROTOTYPE

Fig. 2 presents our prototype for Earable device. The prototype consists of (1) a central control module and (2) a pair of silicon behind-the-ear earpieces. The central control unit holds an ARM Cortex-M4F microcontroller (MCU) and an integrated ultra-low noise amplifier at its heart. They provide the ability to capture microvolt-level electrical biosignal at 1000 samples per second from two ears. The circuit board is enclosed in an electrically shielded 3D-printed closure isolating the circuit from environment electromagnetic interference. The earpieces are molded with skin-safe silicon liquid. We use copper as the base for the electrodes. They are plated with 24K gold liquid to enhance conductivity and resistance against skin oil and sweat. Gold plated electrodes are attached to the silicon earpieces by another layer of silicon liquid. Earable employs wet electrodes in its design, so skin preparation with alcohol is required to remove dead skin and greases. A small amount of conductive paste can be put on the electrodes to lower contact impedance. Afterward, the user can wear the Earable device by placing the silicon earpieces behind their ears and clipping the control module on their shirt.

3 DEMONSTRATION

Our demonstration will present two use cases which are enabled by the technological advancement in biosignal sensing introduced with our Earable platform. The illustration is presented in Fig 1.

Improving relaxation/sleep with sensed brainwaves: In this demo, we demonstrate that by capturing the user's cognitive state, smart devices in the house could be controlled to improve user's relaxation/sleep. In particular, the alpha and beta rhythms, and eye movements will be captured. The alpha rhythm is electrical oscillations in the frequency range from 7Hz to 12Hz generated by the brain when conscious and relaxed. The beta rhythm is oscillations from 12Hz to 35Hz of the brain representing alertness. By combining the power of alpha, beta rhythms, eyes opening and closure, a music player and a smart light can be controlled to play relaxing music and dim the light when the user is trying to relax or sleep. Notably, we calculate the power of alpha and beta band and detect eye-opening and closure. When the user is trying to relax or sleep, we will detect their eyes closure, compare the decreasing beta and increasing alpha powers with certain thresholds. Under these conditions including closed eyes, low alpha band power, and high beta band power, Earable dims the light and plays relaxing music to make the user feel more relaxed.

Hand-free drone control with eyes movements and facial muscle activity: Complete hand-free human-computer interactions are also feasible with our Earable device. This demo presents the control over a drone with user's eye movements (i.e., blink, gaze left and right) and facial muscle contractions (i.e., grind and chew teeth, open and closed mouth). The drone will take off, land, move and rotate accordingly. In particular, we filter our captured signals from two ears in the frequency range from 1Hz to 20Hz containing the eyes blinks and eyes movements and use the frequency range from 50Hz to 100Hz to get the facial muscle contraction. Eye blinks and movements have certain U-shape patterns which can be detected to control the movements of the drone. Furthermore, grinding, chewing, opening and closing the mouth have different power amplitudes which are used to instruct the drone to take off and land.

Our demonstration video is publicly available at the following link[1].

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