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Detection of Microsleep Events with a Behind-the-ear Wearable System

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Abstract—Every year, the U.S. economy loses more than $411 billion because of work performance reduction, injuries, and traffic accidents caused by microsleep. To mitigate microsleep's consequences, an unobtrusive, reliable, and socially acceptable microsleep detection solution throughout the day, every day is required. Unfortunately, existing solutions do not meet these requirements. In this paper, we propose WAKE, a novel behind-the-ear wearable device for microsleep detection. By monitoring biosignals from the brain, eye movements, facial muscle contractions, and sweat gland activities from behind the user's ears, WAKE can detect microsleep with a high temporal resolution. We introduce a Three-fold Cascaded Amplifying (3CA) technique to tame the motion artifacts and environmental noises for capturing high fidelity signals. Through our prototyping, we show that WAKE can suppress motion and environmental noise in real-time by 9.74-19.47 dB while walking, driving, or staying in different environments, ensuring that the biosignals are captured reliably. We evaluated WAKE using gold-standard devices on 19 sleep-deprived and narcoleptic subjects. The Leave-One-Subject-Out Cross-Validation results show the feasibility of WAKE in microsleep detection on an unseen subject with average precision and recall of 76% and 85%, respectively.

Index Terms—Behind-the-ear sensing, Microsleep detection, Drowsiness monitoring, Wearable devices, Cyber-Physical systems.

1 Introduction

More than 65 million people in the U.S. suffer from Excessive Daytime Sleepiness (EDS) due to sleep deprivation, obstructive sleep apnea, and narcolepsy [1]. EDS often results in frequent lapses in awareness of the environment (i.e. microsleeps). Healthy people with sleep deprivation usually experiences microsleep [1]. Shift workers, night time security guards, and navy sailors with sleep problems have a 1.6x higher risk of being injured, causing 13% of all work injuries [2]. Sleepy drivers are at a 3x higher risk of an accident causing one in five fatal car crashes [3]. People with sleep apnea also suffers from microsleep. The microsleep issue due to sleep apnea alone leads to a loss of nearly $150 million every year due to daily work performance reduction and vehicle accidents [4]. Additionally, more than half of Narcoleptic people are unemployed because of uncontrollable microsleep [5]. They often use Amphetamines to keep themselves awake, resulting in many drug overdose cases [6]. Combined, the sleepiness problem of drivers and the workforce costs the U.S. up to $411 billion annually [7].

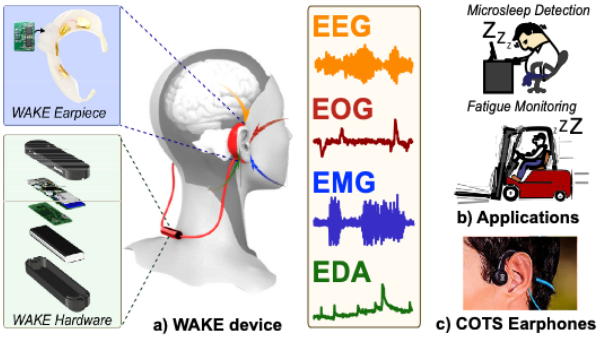

Fig. 1. Biosignals monitoring from behind the ears concept.

Polysomnography (PSG) and camera-based solutions have been used for microsleep detection. In particular, the Maintenance of Wakefulness Test (MWT) using PSG [8] is the medical gold standard to quantify microsleep based on the electrical signals from the human head, such as brain waves, eyes ball movements, chin muscle tone, and behaviors including eyelid closure, eye blinks, and head nods. This method requires a complicated setup performed by trained technicians in a controlled clinical environment.

Using cameras is another solution to detect microsleep. This approach is the most affordable and common method to detect microsleep for drivers [9, 10]. The camera-based approach only captures the outer reflection of sleepiness, such as eyelid closure and head nods and ignores the other physiological signatures of sleepiness (e.g., brain and

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