AttentivU: a Wearable Pair of EEG and EOG Glasses for Real-Time Physiological Processing

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Fig. 1. Side and front views of AttentivU glasses, showing silver electrodes and frame as well as a user wearing them.

Abstract—Recently several research projects have explored using physiological sensors such as electroencephalography (EEG) or electrooculography (EOG) electrodes to measure the engagement of a user in different contexts and augment learning activities. However, these systems still suffer from limitations such as an absence of a socially acceptable design, or use of impractical gel-based electrodes. We present AttentivU, a device using both EEG and EOG for real-time monitoring of physiological data. The device is designed as a socially acceptable pair of glasses and employs silver electrodes as an alternative to the commonly used silver/silver chloride (Ag/AgCl) “wet” electrodes. A detailed description of the hardware design and proof of concept prototype is provided, as well as a side by side comparison of conventional wet electrodes.

Keywords—Electrooculography (EOG), electroencephalography (EEG), silver, electrode, wearable electronics, human-computer interaction (HCI).

I. INTRODUCTION

Everyday work has become increasingly complex and cognitively demanding. Our level of attention influences how effectively our brain prepares itself for action, and how much effort we apply to a task. Information about a person’s attentiveness, or engagement, if integrated into workplace, training or educational environments, could help better understand a person’s habits, interests, and areas of focus and could also be used to improve his/her attention and performance on a task through biofeedback. However, there are currently no convenient systems that inform a person about their attention while they perform a task and help them sustain their attention when they desire to do so.

Prior work in this area focused mostly on providing information to teachers or presenters about the engagement levels of their students or audience [1, 2, 3] rather than informing users themselves such as in [4].

Several recent papers [5, 6, 7] explored measuring engagement using physiological sensors such as electroencephalography (EEG). EEG signals can be used to identify subtle shifts in user alertness, attention, perception, and workload in laboratory, simulation, and real-world contexts [8; 9; 5]. The problem with these EEG-based systems mostly relies in the form-factor used: the electrodes are usually embedded in either a cap or a headband. Though there is a recent shift in commercially available systems from multiple electrode, several thousand dollars systems towards 1-3 electrode setups costing $200-300, even a compact headband is not quite considered to be a compelling and socially acceptable form-factor.

Looking at other body signals, another physiological measure for monitoring engagement is electrooculography (EOG). EOG is based on measuring the biopotential signals that are induced due to cornea-retina dipole characteristics when there is eye movement. EOG has been used to show that...
blink rate decreases as cognitive load increases [10]. Researchers have also shown that eye movements correlate with the type of memory access required to perform certain tasks, and are good measures of visual engagement and drowsiness [11, 12]. However, current EOG systems face similar issues to EEG headbands: they are either embedded in headbands and head caps like [13, 14] or they are attached to frames of glasses with wires and are not convenient or comfortable for real-life use [15, 16].

To the best of our knowledge, there are only two pairs of glasses that use either EEG electrodes or EOG electrodes (Fig. 2): Smith Lowdown Focus Eyewear Glasses [17] by Muse and JINS MEME glasses [18]. Smith Lowdown Focus Eyewear is a light-weight, dry-electrode pair of EEG glasses with two electrode sites TP9 and TP10 according to the 10–20 EEG positioning system. JINS MEME glasses have three-point EOG sensors on nose-pads, three-axis accelerometer sensors and three-axis gyroscope sensors. Both require the glasses to be used together with a secondary device such as a phone. These two glasses each use a single physiological input modality. As both EEG and EOG modalities have limitations for measuring attention and engagement of a user, based on the state of the art, we believe that there is a possibility of obtaining more accurate measurements if both physiological sensing modalities as well as a feedback option are provided within one device.

Our focus with the AttentivU glasses is on developing a better solution for attention monitoring and feedback delivery based on our previous work [19]. We built wearable glasses (Fig. 1) that 1. look socially acceptable so they can be worn in real-life situations and 2. the feedback delivery is provided in real-time in the form of an auditory signal via bone conduction speakers and does not require any other device to be used.

![Fig.2 From left to right: Smith Lowdown Focus Eyewear Glasses; JINS MEME glasses and our prototype of AttentivU glasses.](image-url)

II. SYSTEM ARCHITECTURE AND FIRMWARE

The system architecture of the glasses is modular (Fig. 3) so as to facilitate easy integration of different input modalities and feedback options. Surface biopotentials for EEG and EOG are acquired with electrodes embedded in the glasses (Fig. 5). Given the low amplitudes and noise of EEG and EOG, the signals are processed in the analog domain before being converted to digital data as explained below.

A. Processing Module for EEG

The biopotentials are amplified with a micro-power precision instrumentation amplifier, with gain calibrated to ~10V/V, referenced to the EEG reference regulated by the power management system discussed below. The rail-to-rail output is filtered through a cascade of first-order low-pass and first-order high-pass filters with cutoff frequencies around 50Hz and 0.5Hz respectively. The filtered analog signal is amplified with a micro-power CMOS operational amplifier with gain calibrated to ~100V/V. This amplified signal is again passed through a copy of the cascade of first-order filters discussed above, and an operational amplifier with gain calibrated to ~40V/V. The amplifiers used feature low offset voltage, near-zero drift over time and temperature, low noise and very high Common-Mode Rejection Ratio (CMRR). The entire preprocessing discussed above offers a gain of ~40000V/V, a bandwidth of around 0.5 to 50Hz, input impedance over 100GOhm, and CMRR over 100dB, while consuming merely ~3mA of power regulated at 3.3V.

B. Processing Module for EOG

The biopotentials are fed to a low-power integrated signal conditioning block featuring a high signal gain of ~10V/V and a high CMRR of 80dB (dc to 60Hz). The passive components around the AFE (analog front-end) further provide a gain of ~10V/V and a first-order bandpass filter with cutoff frequencies around 0.5Hz and 40Hz. The entire preprocessing discussed above offers a gain of ~1000V/V, a bandwidth of around 0.5 to 40Hz, input impedance over 100GOhm, and CMRR over 110dB, while consuming merely ~4mA of power regulated at 3.3V.

C. Microcontroller and Bluetooth

The processed EEG and EOG signals are fed to a high-performance, low-power (1.0mA idle / 3.9mA active supply current at 3.3V) 12MHz microcontroller featuring an 8-channel 10-bit Successive-approximation-register (SAR) Analog-to-Digital Converter (ADC). The digital data sampled at 1000Hz is sent over Universal asynchronous receiver-transmitter (UART) to a low-power, high-performance Bluetooth module featuring a 2.4GHz antenna, for transmission of data with maximum signal delay of <50ms. While the Bluetooth module provides transmission of EEG and EOG, it can also receive feedback signals and send them to the microcontroller over UART. The microcontroller provides output options for visual, haptic or auditory feedback. Auditory feedback is delivered via bone conduction through a piezoelectric transducer, max consumption 5mA for 65dB at 3V.

![Fig. 3. System architecture of AttentivU glasses.](image-url)
D. Power Management System

A dedicated power management system was designed primarily for voltage regulation of analog circuits, microcontroller and Bluetooth, and battery charging with LED indicators. A 3.7V 150mAh Lithium Polymer (LiPo) battery powers all the electronics for about 5 hours, given the current draw is ~30mA. An alternate LiPo battery measuring 29x36x4.75mm can be attached externally, improving a single-charge battery cycle to 15 hours. A micro USB slot has been provided for charging the battery. The charge time is indicated with an orange LED. The battery voltage is also monitored with the ADC of the microcontroller, which turns on a red LED to indicate low battery referenced upon a threshold. A blue LED indicates when the device is on and is acquiring data.

E. Firmware

The source code is written in C and is modular for easy integration of other input modalities and feedback options. The main block of code configures pins and EEPROM/memory variables, sets timers for output updates, and initializes the interrupt handler. Other firmware methods handle the ADC conversion central to the microcontroller for all analog - physiological (EEG and EOG) and battery voltage data and data transfer over Bluetooth.

Apart from the on-board analog filtering, the microcontroller offers enough hardware resources and processing power to handle the signals in digital domain in real time and filter them as required before transmitting them over Bluetooth.

III. FRAME AND ELECTRODES DESIGN

The frame of the glasses is designed to carry two PCBs, two EEG electrodes, two EOG electrodes, a reference electrode, and a LiPo battery (Fig. 4). Internal wire routing is used to carry signal from each of the electrodes to the PCBs, and to transfer power and data between the PCBs housed in the glasses' temples. Selected components of the glasses frame are made from pure silver to serve as the electrodes for EEG and EOG. The temple tips of the glasses frame are the EEG electrodes, which corresponds to two electrode sites TP9 and TP10 according to the 10–20 EEG positioning system. The nose pads are the EOG electrodes. At the nose bridge of the glasses, an extra silver plate is placed to serve as reference electrode (Fig. 5). The frame is made from Nylon Plastic which is a flexible material, allowing the frame to snugly fit around a user’s face (Fig. 1).

We initially used aluminum as the electrode material; however, the signal was weak and the material was prone to oxidizing, which jeopardized conductivity. We next fabricated the electrodes in Silver given its high conductivity (~ 63m Siemens per meter) compared to other metals, copper being ~ 59.6m Siemens per meter and aluminum ~ 35m Siemens per meter [20].

IV. VALIDATION OF THE SIGNALS

In order to validate the functionality of the glasses and for proper comparison of any measurement results when using the glasses in studies, EOG as well as EEG signals were collected using both classic Ag/AgCl and our silver electrodes (Fig. 5). We used our PCB with Bluetooth transmission for recording in both setups.

For EOG recording, the user was instructed to look to his left and then to his right without making head movements or any other movements. Although the amplitude and signal quality of our silver EOG electrodes are lower than for the wet EOG electrodes, amplitude variations due to eye movement are clearly observed in the signal (Fig. 6).

For EEG recording, the user was instructed to close his eyes and to keep them closed without performing eye movements, head or other movements. For another short validation test we instructed the user to clench his teeth strongly, without performing additional movements (Fig. 7). As we can see in Fig. 7, the signal quality of the EEG signal obtained from the silver electrode corresponds to the one obtained from Ag/AgCl ones.
We demonstrated the feasibility of embedding silver EOG and EEG electrodes in a socially-acceptable form factor of a pair of eyeglasses. We have recorded several eye movements and other types of activities such as eyes closed or teeth clenching using our silver electrodes and the recorded EOG and EEG signals were in good agreement with data acquired using conventional Ag/AgCl electrodes. All the experimental tasks performed are clearly recognizable in the data from both the wet and silver electrodes. The signals can be processed in real time with the on-glasses processor or optionally sent to a separate computer. To the best of our knowledge, this is the first prototype of glasses that uses the same type of electrodes for bimodal setup. We hope that having access to both EOG and EEG data will be a compelling data source for several applications including attention monitoring for improved well-being.

V. CONCLUSION

We demonstrate the feasibility of embedding silver EOG and EEG electrodes in a socially-acceptable form factor of a pair of eyeglasses. We have recorded several eye movements and other types of activities such as eyes closed or teeth clenching using our silver electrodes and the recorded EOG and EEG signals were in good agreement with data acquired using conventional Ag/AgCl electrodes. All the experimental tasks performed are clearly recognizable in the data from both the wet and silver electrodes. The signals can be processed in real time with the on-glasses processor or optionally sent to a separate computer. To the best of our knowledge, this is the first prototype of glasses that uses the same type of electrodes for bimodal setup. We hope that having access to both EOG and EEG data will be a compelling data source for several applications including attention monitoring for improved well-being.

REFERENCES

Focal/Lowdown-Focal/p/LFCMBRVMGV