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A Low-Cost, Wearable, Portable EOG Recording System

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***Abstract*— This paper describes a new low-cost, wearable and portable system to acquire Electro-oculogram (EOG) signals. The system comprises of three electrodes for recording EOG, an instrumentation amplifier and signal conditioning unit, and a general purpose computer with a custom made EOG analysis software. A special type of signal acquisition arrangement has been made where the electrodes are embedded in a frame of a spectacle that provides adjustable settings for different head sizes. The electrodes comprise of dry Ag-AgCl sensors for acquiring the data. The software consists of preprocessing options such as sensor noise removal, power line noise removal, blink detection, saccade detection, etc. The system has been tested against a standard commercial Polysomnography system.**

Keywords—EOG, EMD; ICA; Embedded devices; BCI

I. INTRODUCTION

As humanity progresses towards a better tomorrow, we not only enter an era of intelligent devices and smart technologies but also for inexpensive solutions. It has been a challenge to the Bio-Instrumentation and Bio-Sensors community to provide effective, cheap solutions for biomedical signal acquisition devices. This paper proposes a low-cost yet effective solution to acquire Electrooculography (EOG). EOG is a bio-signal which refers to the standing potential between the cornea and the retina [1]. It is widely used in the analysis of eye movements, eye health-care as well as cognitive studies[2].

There are several applications which have been developed, based on EOG acquisition. The most impressive application based on EOG signals is in assistive robotics based on wireless EOG technology and RFID control architecture which aims to create a helping hand for people suffering from motor control disorders [3], [4]. Another illuminating example is in controlling wheel chairs for neurologically affected people using EOG signals [5]. Mouse cursor control can be implemented using EOG, leading to increased interaction with the computing world for people with severe neurological conditions and damages [6]. Text entry by the use of a virtual keyboard can be achieved using eye gaze trackers, which also contributes towards a hands-free future[7]. Home appliances can also be controlled by using wearable tech, enriching amputee's and people with disabilities[8], and contributing towards a smart home [9]. Even the use of glasses as a sensor mount for emulating a mouse is an age old concept[10]. The above review enlightens the importance of EOG as an effective bio-signal.

Commercial EOG acquisition systems are hardly available as a single dedicated unit. Even if they are available, the price of the device becomes a major issue. Most EOG capturing devices come as a part of either EEG systems or as a polygraph. These devices have many extra functionalities which are not required for people working exclusively on EOG.

This work describes a novel spectacle based system designed for a cheap and portable system for acquisition of EOG signals and analysis of EOG signals to extract eye movement based parameters for use in cognitive exploration.

II. DEVICE DESCRIPTION

The first step in the process is the design of the system to acquire EOG signals. The system consists of three major units.

a) Goggles – Data Acquisition

The primary piece of the design is a goggles (shown in Fig. 1) where the electrodes for recording the EOG are connected as shown in components 1, 2, and 3. Three electrodes are present – one on the forehead and two on distal ends of the eyes. EEG paste has to be applied properly to ensure noiseless recording. The electrodes are dry Ag-AgCl electrodes. The electrodes on the distal ends of the eye are active electrodes (AE), and as such they don't require skin preparation; as compensation is achieved using an amplifier with high impedance. The electrode on the forehead is a passive electrode, without active compensation.

The AE has the following properties:

1. When using AEs instead, no skin preparation is required, and better performance can be achieved under imperfect conditions.
2. It takes +5V.
3. Not water resistant
4. Highly sensitive to dust
5. 1m long cable

The PE has the following properties:

1. It is used as the reference.
2. It takes +5V.

3. Not water resistant.
4. Highly sensitive to dust
5. 1m long cable

The AE and PE are shown in Fig. 3 and Fig. 4 respectively (courtesy [11]).

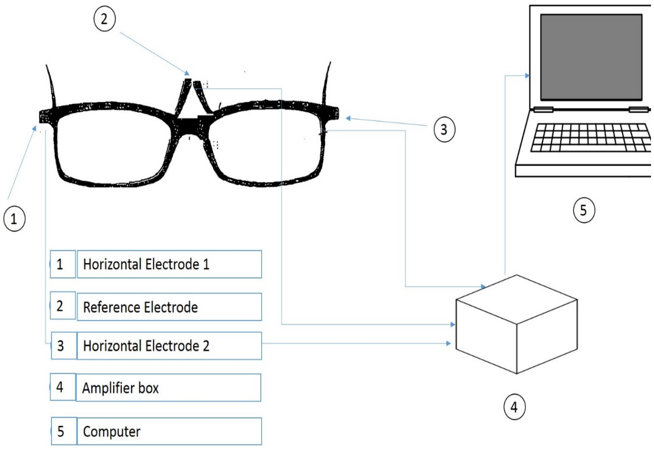

Fig. 1 The overall system schematic

Fig. 2 Spectacles for EOG recording

Fig. 3 Active Electrode

Fig. 4: Passive Electrode

a) Signal acquisition board-

The signal acquisition board is basically two sets of amplifier and ADC boards, each bearing two bipolar channels and single digital board, which is controlled by an AVR32 micro-controller and is interfaced with an FTDI port which communicates with a PC to carry the raw signal to the PC. This is shown in Fig. 5 (courtesy [11]). This device is created under the Creative-Commons license and as such is totally free in use, share, and development.

Fig. 5 EOG Recorder with all connections shown

- **Power:** This board is self-powered by the USB port. Additionally the board can be powered using the 10pin ICSP connector. 20 seconds after powering the board PWR should go RED. The current consumption is around 0.8A. When it is connected via a USB cable to a USB host, it will take its 5V power supply from the USB host source to power the board.
- **Electrostatic Warning:** The EEG-SMT development board is shipped in a protective anti-static package. The board must not be exposed to high electrostatic potentials. A grounding strap or similar protective device should be worn when handling the board. Avoid touching the component pins or any other metallic element.
- **Dimensions:** 3.2 inch x 1.8 inch x 1 inch
- **No water or dust protection**
- **Operating Temperatures:** The capacitance of all ceramic capacitors changes with temperature,

voltage, frequency and over time. Hence, ideal working temperature is within $20^{o}\ C$ to $50^{o}C$.

- **Weight:** 35 gms

b) The analysis toolbox-

The third piece of the system is the custom made software on the PC, which acquires and analyzes the EOG data. The software on execution asks for 'Name' and 'Unique Id.' Thereafter, an instruction comes requesting for permission to record the EOG. Once the recording is over, the data will be displayed after processing of the saccadic parameters. This tool is compatible with Windows 64 as well as 32 bit systems.

III. EOG Recording and Analysis Software

The EOG software comprises of two parts – recording and analysis. The software can run on any x86 as well as x64 architecture system.

A. Recording

This part of the software samples the EOG data at 256 Hz and stores it in .xls format. The duration is specified by start and stop buttons.

B. Analysis

This part mainly consists of filtering, blink detection and saccade detection.

Filtering: The sensor noise is removed using Empirical Mode Decomposition using the algorithm provided in [12]

Blink Detection: This is accomplished using Independent Component Analysis [13].

Saccade Detection: This has been accomplished using our earlier work as provided in [14].

IV. Results

Outstanding features of device

1. Very low price compared to professional EEG/EOG/PSG devices
2. Compact size
3. Solid plastic case
4. Powered by USB
5. ICSP10 interface for reprogramming
6. Fully open software and open hardware

The EOG data is analyzed through a GUI, which takes the input of filename and channels and looks as shown in Fig. 6.

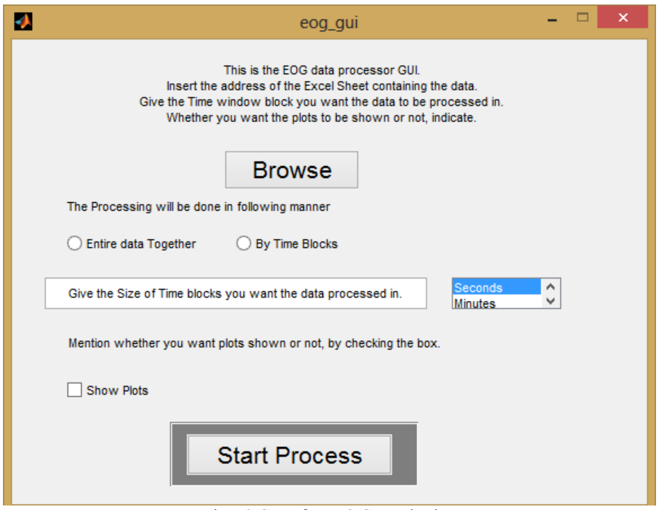

Fig. 6 GUI for EOG analysis

It supports the processing of EOG data both as a complete set and also as broken into separate time segments. The examples of the Raw EOG data captured using the device and the smoothed and truncated EOG data as processed by the GUI are shown in following figures as follows –

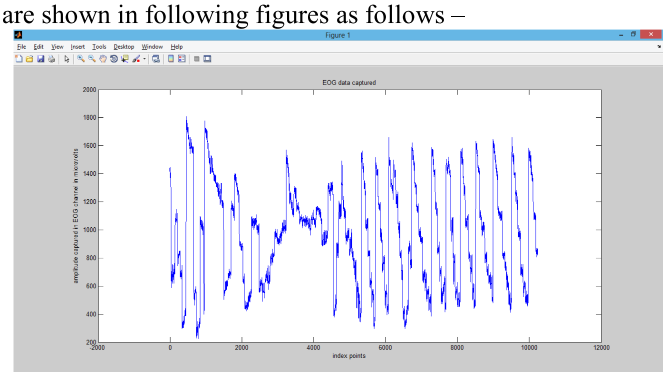

Fig. 7 Raw EOG data

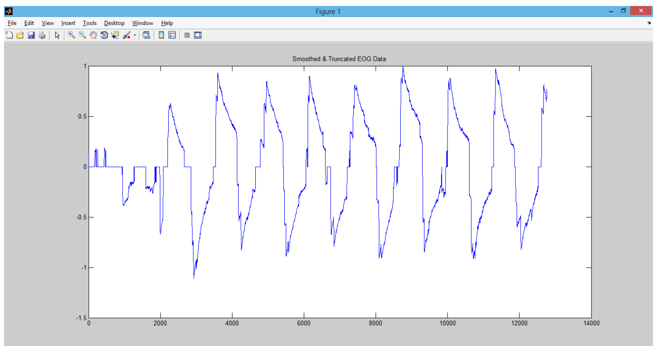

Fig. 8 Smoothed and Truncated EOG data

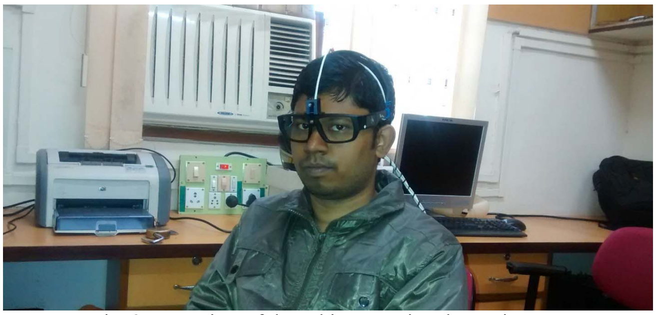

Fig. 9 Front view of the subject wearing the equipment

V. CONCLUSION

In this paper, we propose a novel design of a device for the acquisition and analysis of EOG data. The device is low-cost, portable and wearable which offers advantages over the existing devices. The device can be used to obtain measures of several cognitive activities such as drowsiness and vigilance. This concept can be further extended into the design of a gaze tracker by the use of both vertical and horizontal channels of EOG.

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