Measurement 127 (2018) 481–488

Contents lists available at ScienceDirect

Measurement

journal homepage: www.elsevier.com/locate/measurement

Development of an EOG-based system to control a serious game

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ARTICLE INFO

Keywords:
Electrooculography (EOG)
Disabled people
Machine learning
Serious games
Wavelet transform

ABSTRACT

Eye movements are the least affected by disabilities of the central motor system. This means that eye movements have great potential in the development of applications adapted to people with motor disabilities. This article describes the development of an electrooculography (EOG) system to control a serious computer game. The goal is to allow people with motor disabilities to play a serious game and improve control over their oculomotor systems. The developed system consists of three subsystems: a low-cost hardware device to acquire the EOG signals, methods to process them digitally, and a serious game controlled exclusively by eye movements. Fourteen able-bodied volunteers of different ages and genders tested the computer game. The evaluation of the system's interaction capacity with the computer game was based on three metrics: score obtained, number of successful interactions, and number of errors committed.

1. Introduction

In recent years, research into developing assistive systems for people with disabilities of the central motor system has increased with the aim of affording them a more autonomous lifestyle and greater social inclusion. In this regard, diverse assistive technologies have been developed based on the detection and tracking of the eye gaze. This is because eye movement is the motor skill least affected by this type of disability [1]. However, eye tracking remains a challenging task today, as disabled people need training to achieve effective control over their oculomotor system [2–5].

The main current eye tracking technologies, including video-oculography (VOG), infrared oculography (IROG), and electrooculography (EOG), are based on measuring angular eye position relative to the head. Research on EOG has involved investigating the human oculomotor system [6], exploring control of human prostheses [7], assessing driver drowsiness [8], and studying ergonomics [9]. Several studies have also focused on the development of robots [10–12], electrical wheelchairs [13,14] and graphical user interfaces (GUIs) controlled by eye movements [15–21].

In EOG, the eye behaves as an electric dipole in which the cornea is the positive pole and the retina the negative pole, so that eye movements cause variations in the potential of the dipole. This potential depends directly on the angle of the eye's gaze (see Fig. 1) and forms the foundation of EOG signals, which are recorded using simple electrodes around the face. The recording is very fast; thus, translating eye movements into commands makes real-time implementation possible [22–29].

The goal of such work is to allow people with motor disabilities to play a serious computer game. This type of game can serve as an entertainment tool for disabled people as well as help them improve control over their oculomotor system. The developed system consists of three subsystems, as shown in Fig. 1: a hardware device to acquire the electrical signals corresponding to eye movements (EOG signals), methods to digitally process them, and a serious game controlled exclusively by eye movements.

The rest of this article is structured as follows: Section 2 presents relevant related studies. Section 3 describes the materials and methods used to acquire and process EOG signals. Section 4 describes the EOG-controlled serious computer game, which Section 5 discusses, and Section 6 presents the conclusion.

2. Related work

In general, research on EOG technology has focused on specific parts of the system presented in Fig. 1 but not the whole system. About the design of hardware devices for EOG signal acquisition a variety of references can be found [2,3,18,30–32]. Expensive commercial bio-signal amplifiers can also be used to acquire EOG signals [33–37].

The use of wavelet transform as a method for denoising EOG signals

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https://doi.org/10.1016/j.measurement.2018.06.017
Received 6 April 2018; Received in revised form 8 June 2018; Accepted 11 June 2018
Available online 15 June 2018

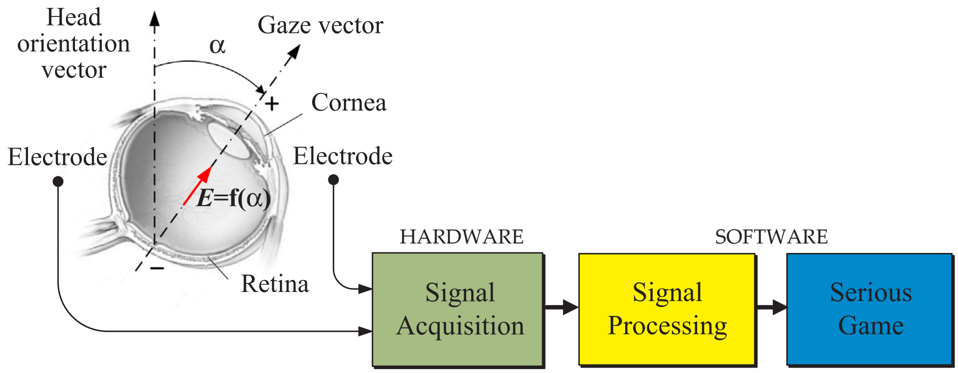

Fig. 1. Block diagram of the proposed EOG system.

has gained special relevance in recent years. Several studies have discussed the convenience of using continuous wavelet transform (CWT) [38,39], discrete wavelet transform (DWT) [15], or stationary wavelet transform (SWT) [40]. On the other hand, to classify EOG signals, several machine learning techniques have gained attention [15,20,41,42] rather than voltage thresholds [21,43,44].

However, with respect to EOG-controlled serious games, only two studies are available. One [45] presents a simple interface that instructs the patient to follow and blink at highlighted numbers in a 4 × 4 grid. The authors, however, do not consider it a game for training the oculomotor system. The other [46] presents an eye-movement tracking system with two functionalities: controlling a TV and playing a game. The game is very similar to the famous Tetris game, but in this case the user must match balls of the same color. The purpose of this game is to entertain the user without intending any other kind of applicability.

3. Materials and methods

Following the block diagram in Fig. 1, this section presents the key points about EOG signal acquisition and processing.

3.1. EOG signal acquisition

The first challenge is to acquire EOG signals with minimum interference. Fig. 2 shows a block diagram of the hardware device together with suitable electrode placement to acquire the signals [47,48]. The device consists of two identical acquisition channels to record horizontal and vertical eye movements. The electrodes are connected to the channel inputs with resistors in series to limit the current from reaching the human body and thus comply with safety standards [49]. To protect the input circuit itself against defibrillator discharge, transient voltage suppression diodes are placed between each electrode and the ground, thus serving as a high-impedance component.

The EOG signal must be amplified and filtered. Its amplitude and bandwidth are in the range of 50 to 3500 μV, and its frequency varies from 1 to 50 Hz [50,51]. The main source of interference is the 50/60 Hz power line interference and electromyography (EMG) signals. The EOG signal also depends on many other factors, such as electrode placement, skin–electrode contact, head movements, and blinking [2,52].

In the first stage, an instrumentation amplifier (IA) is devoted to amplifying the voltage difference between the two electrodes in each channel. The gain of this IA is set to 20 V/V in such a way that the electrode DC offset does not saturate the IA. Although the IA has a high common mode rejection ratio (CMRR), reducing the user's common mode voltage is necessary. The reference electrode, together with a negative feedback circuit, minimizes the common mode voltages. This solution is very common for recording biopotentials [53,54].

The second stage involves a band-pass filter (BPF), which consists of a high-pass filter and a low-pass filter. The second-order high-pass filter, with a cutoff frequency of 0.05 Hz, removes lower frequency interference from electrode placement, skin–electrode contact, and head movement. The second-order Bessel 30 Hz low-pass filter minimizes the 50/60 Hz power line and EMG interference.

Once the DC component is removed, a second amplifier regains the signal. The gain of this second amplifier can be set between 1000 and 5000 V/V with a programmable gain amplifier (PGA). Then, a potentiometer provides the bias voltage to the amplifiers to obtain positive output voltage, thus adapting the signal to analog-to-digital converter (ADC) input.

To achieve signal digitalization, a 10-bit ADC embedded in a microcontroller device (AT90USB64) codes the EOG signals using a 10-characters format, XXXXYYYY\r\n, where X and Y represent a decimal value of the horizontal and vertical channels respectively, "\r" is the carriage return, and "\n" is the line break. For instance, XXXX can be between 0000, when no eye movement occurs, and 1023, when the eye movement is at maximum. The microcontroller carries the ADC output to the Bluetooth device (BlueGiga WT12) at a transmission rate of 9600

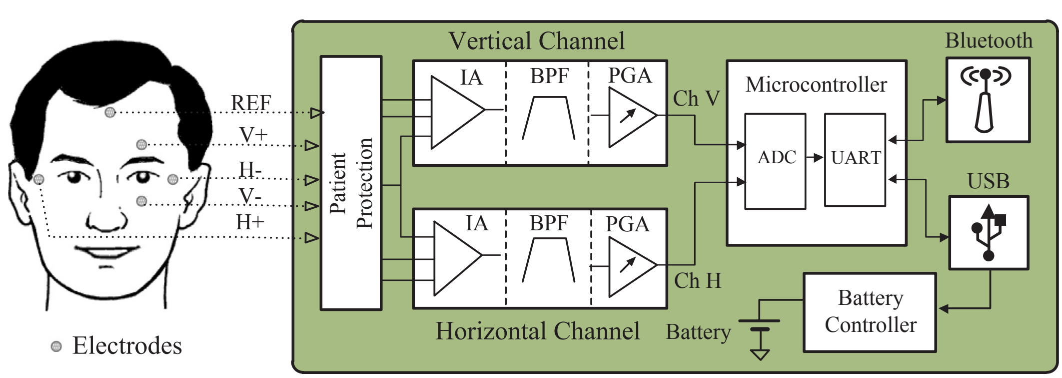

Fig. 2. Block diagram of the hardware device.