Identification of saccades in Electrooculograms and their use as a control tool
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Abstract: This paper describes the tasks carried out to develop a control tool using the changes detected in gaze, which are captured in the electrooculogram signal. The objective is to use these changes to control a user interface such as Dasher. A software tool for generating visual stimuli and acquiring the eye signal has been developed. These signals were later processed with a first derivative-based algorithm in order to detect the changes. The optimal parameters for the algorithm have been determined, and also the sensitivity (S>97%) and the predictive positive value (+PV>90%) of the detector have also been calculated. The preliminary results are promising, but a study with a greater number of individuals should be made to check the on-line performance with longer registers.

Key-Words: electrooculogram, saccadic movements, dasher, acquisition, control

1 Introduction

The use of gaze-tracking techniques as control systems is a work that has been increasing in recent years [1],[2]. The main idea is to control devices with eye (or gaze) movements. These movements are extremely fast, so is greater than the response speed achieved with a pointer, e.g., a mouse.

This work presents an acquisition, processing and electrooculogram (EOG) analysis, as an initial stage to use the EOG signal in an open source, free tool called Dasher [3]. This program enables optimal writing in a text editor that is controlled by on-off signals. The authors propose the use of EOG and a modified version of the Dasher software as the base system to develop control device systems for severely handicapped people.

This paper is aimed at the acquisition of EOG signals, and the generation of visual stimuli that will generate the saccadic movements, the authors also propose an algorithm to characterize movements of this kind. This control signal could be used in the future as a pointer control in the Dasher software, leading to a fast writing tool for the handicapped, or they can also be used in several applications, such as alarm systems[4], wheel chair guidance[5], etc.

2 Problem Formulation

2.1 Dasher

Dasher (www.inference.phy.cam.ac.uk/dasher/) [3] is a text-entry system that has a novel interface incorporating a language model. Text typing is driven by continuous two-dimensional search and navigation with a device such as a mouse, touch-screen, rollerball, breathing device, or eye-tracker.

Figure 1. Main screen of Dasher.

The language model has been trained on example documents, or training corpus, which allows Dasher to predict the probability of each character’s occurrence in a given context. The size of the space is allocated for each setter and successive characters according to the predicted probability. A screen shot of Dasher is shown in Figure 1. Dasher is licensed
under GPL and is available for several operating systems, including Windows, Linux and Pocket PC.

2.2 Electrooculogram acquisition

Several practical devices have used eye movement as a communication support. The video-oculogram, which detects eye movements from pictorial images of the eyeball, requires a video camera to film eye movements in real time. Eye movement detection using infrared reflectance of the cornea is difficult to use over a long period of time because eyes tend to become dry and fatigued [1]. All of these different techniques have advantages and drawbacks, and their use is intrinsically related to the target of research or the specific purpose desired. Eyes control their movements by the use of six muscles that enable them to perform different kinds of movements: saccades, fixation, and smooth pursuits [6].

In basal conditions, the retina has a bioelectrical potential that is negative with respect to the cornea. The registering of this potential, called EOG, can be done by using surface electrodes placed around the eye. It is a non-invasive technique and can be used as a marker of eye movements. This technique measures eye movements relative to the head position and is not generally suitable for point of regard measurements unless the head position is also measured [7]. This potential is corrupted with several sources of noise which makes the amplification stage a critical component. The typical spatial resolution when using surface electrodes is ±1.5°-2°[5].

There are some problems associated with EOG measurement. Eye blinks and eye-muscle electrical activity contaminate the signal; moreover, there is a considerable wandering of basal line due to electrode drift. All these factors are considered as noise overlapping to the target signal and must be eliminated using digital processing techniques as a previous step before signal interpretation. With this method, the final signal can be used as a control signal. Electrooculogram signals have bandwidth between DC and 10 Hz. The amplitude ranges from 15 μV to 200 μV and is linearly related to the eye displacement, with nominal sensitivities of about 20μV/deg. An important problem of this bioelectrical potential is the DC component which may saturate the amplifier.

A set of five electrodes Ag/AgCl has been used in the acquisition of the signal, located at the positions shown in Figure 2. These potentials have been amplified using the g.BSamp module from Guger Technologies. This module is an AC-coupled amplifier with a cut-off frequency of 0.01 Hz; with this method, the typical saturation of DC coupling is avoided. In order to reduce skin impedance, the skin was cleaned with an abrasive gel, Parker Redux Paste. Every register consists of a horizontal channel (channel H) and a vertical channel (channel V), which should enable the detection of changes in both directions.

Figure 2. Layout of electrodes used in the acquisition of EOG registers.

Since we are solely interested in the measurement of abrupt eye movement (saccadic), an analysis of the obtained waveform was made in order to be able to determine which sampling frequency was most suitable and thus to determine the antialiasing filter to be used. Finally, we decided to use a sampling rate of 20 Hertz per channel and to limit bandwidth by means of a 2nd order analogue Butterworth filter with a cut-off frequency of about 4 Hertz.

The entire amplifying system is powered by rechargeable batteries, and also has galvanic isolation to guarantee the safety of the patient. The amplified signal is the input of a data acquisition card (PCL 711B of Advantech) with 12 bits of resolution. A program has been developed that enables the user to simultaneously control, the acquisition of the EOG signals and the generation of visual stimuli; the position and the duration of the stimuli are selectable parameters. Figure 3 shows the positions in which visual stimuli appear. Each stimulus lasts 2 seconds. Only one stimulus is visible at a time.

Figure 3. Locations of the visual stimuli (only one will be visible at a time).

The visual stimuli are yellow circles on a black background. The distance of the subject to the monitor has been fixed to 50 cm. and a 17-inches screen has been used. The height of the chair has also
been fixed, so that the line of the eyes is approximately in the centre of the screen. Thus, watching the central point does not imply displacement of the eyeball. Additionally, the patient are asked not to move their heads during the acquisition.

2.3 Saccadic movements’ detection

The problem, (extremely simplified), is shown in Figure 4; this figure shows an ideal EOG signal, with saccades and fixations. This signal represents the movement of the eye in only one direction; either horizontal or vertical. It is important to note that we are not interested in the exact point of the eye gaze but in an estimation of the direction (left, right, up and down).

Figure 4. Representation of an ideal EOG signal along with the desired detection marks.

Figure 5 shows a register in which transitions have taken place up-down and later left-right. This figure shows that they are independent movements. Figure 5 also clearly shows the presence of blinks in channel V, which we can consider to be impulsive noise.

2.2.1 EOG registers

Type I registers. In this type of register, there are transitions that only affect one channel. They are composed of repeated patterns up-down or left-right. Thus, the EOG signal only reflects changes in one channel. Figure 5 shows an example of a type I register. The number of type I registers is 16.

Type II registers. In this case, the registers are generated using a sequence with simultaneous vertical and horizontal transitions. According to the numbering in Figure 3, the sequence follows the locations: [5,1,3,9,7,1,5,1,5,3,5,9,5,7,5,2,6,8,4,2,5…2,5,6,5,8,5,4,5,2,8,5,6,4,5,1,9,5,3,7,5]. Figure 6 shows an example of a type II register. The number of type II registers is 18.

Figure 5. Example of a type I register which shows the effect of eye blinks, mainly in channel V

Figure 6. Example of a type II register. In this case, there are simultaneous transitions in both directions.

3 Problem Solution

3.1 Saccadic eye movement detection

We have used a variation of the algorithm based on the point-to-point derivative of the signal in order to determine the position of the gaze, among the different techniques described in [6]. The algorithm operation is the same for both H and V channels. A simplified pseudo code is shown in Table I. The main difference with the originally proposed algorithm is that a median filter is first applied to the signal. Since the length of the filter is similar to a blink, blinks are eliminated. In order to estimate thresholds on the derivative, we distinguish between positive and negative slopes because the eye line is not always in the middle of the screen.

In order to determine the optimal performance of the algorithm, the slope threshold ($slope_{th}$) and the median filter length ($MF_{length}$) must be selected.

The parameter $slope_{th}$ is a factor that multiplies the average of the signal derivatives in the transition
points determined by the stimulus pattern. We have used the first 25% of the known transitions for parameter estimation.

Table I. Pseudocode of the proposed algorithm.

3.2 Results
Many tests were performed on the free parameters and useful information about the optimal values was obtained. The values given to the free parameters were $slop_{th} = 0.2:0.02:0.9$, and $MF_{\text{length}} = 2:2:14$, where MATLAB™ notation was used (InitialValue:Step:FinalValue). The parameters that were used for optimal value selection were the sensitivity and positive predictive value value of the saccadic eye movement detector. The optimum values were:

Type I registers: $slop_{th} = 0.6$; $MF_{\text{length}} = 0.5s$;

Type II registers: $slop_{th} = 0.4$; $MF_{\text{length}} = 0.5s$;

Figures 7 and 8 show the result obtained when applying the algorithm to a type I and a type II register, respectively. A dot marks the points with negative slope, and an asterisk marks the points with positive slope. The determination of the direction of the movement depends on the channel being considered.

Table II shows the results of algorithm sensitivity and positive predictive value (+PV) when applied to all the registers. We have separated H and V channels, and positive (Hp, Vp) and negative (Hn, Vn) transitions. The number of transitions was $N_h=256$ for type I registers and $N_h=270$ for type II registers.

4 Conclusions
The first conclusion that we observed from the acquired registers is that the changes in the direction of the gazes are appraised clearly in both channels, with the vertical channel being the noisier one due to the presence of impulsive noise generated by involuntary blinks. Significant base line wander is observed in the registers, this is due to the extremely low cut-off frequency of the HP filter that sometimes can saturate the amplifier and present signal values that are different from zero even though an individual is watching the centre of the screen. This effect is also generated due to an inappropriate positioning of the patient.

Table II. Results of the saccadic eye movement detection algorithm. S: sensitivity(%). +PV: Positive Prediction Value.

The proposed algorithm is quite simple because it only uses a median filter of length similar to the duration of a blink, and it uses the derivative for the detection of transitions. Derivative thresholds are determined in an initial training stage of the system. The application of the algorithm on both types of register have yielded good detection results in both channels, although the horizontal channel always yields better results due to the lower amount of noise.

The authors are working on combining the output of the algorithm with the Dasher software, which is
currently limited to text typing software but whose operation can be extended for other purposes. The final goal is to use the EOG signal as a control signal for a Human-Machine Interface to detect transitions rather than to detect the absolute position of the gaze. Another possible use of this signal could be as an alarm signal for individuals with severe handicaps.

Figure 8. Results of the saccade detection algorithm in a type II register: (a) Horizontal channel, (b) Vertical channel.

Even though the preliminary results are promising, a study with a greater number of individuals should be made in order to check the online performance with longer registers. In this study, thresholds should be updated on-line

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References