Demystification of Electrooculogram Signals: An Introductory Approach to Activity Recognition

Conference Paper · December 2014

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Demystification of Electrooculogram Signals: An Introductory Approach to Activity Recognition

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Abstract: Eyes are the windows to brain and the eye movements are rich source of information in information processing. The aim of this paper is to present an investigation of eye movements using EOG applications in Human Computer Interfaces (HCI) and classification of EOG signals using Support Vector Machine (SVM). The objective is not to give a detailed explanation about the theoretical background but to impart the fundamental functionality to get an extensive understanding how EOG signals can be applied in HCI and what can be inferred from those signals using Support Vector Machine. This paper is organized as; the first section identifies the importance of eye movements and presents various eye movement detection methods. The second section illustrates the applications of EOG as Human Computer Interface and demonstrates ElectroOculoGram (EOG) signals in data mining aspect. Final section focuses on activity recognition by EOG signal classification using SVM.

Keywords: EOG, HCI, SVM, Classification

1. Introduction

1.1 Eye Movement Interface

Eye movements can be recorded by using a wide variety of methods (Wolfe & Eichmann, 1997; Young & Sheena, 1975) and are extremely informative as a data source for analysis of human cognition [1, 2]. Eye movements can be used as one of the prosperous source of information in information processing. There are broadly two types of eye movements' namely voluntary and involuntary movements of the eyes. Some of the interfaces used for detecting eye movements are listed in Table 1. Researchers have studied eye movements to understand user behavior in basic interface tasks (Aaltonen, Hyrskykari, &Räihä, 1998; Byrne, Anderson, Douglass, & Matessa, 1999), to reveal how users encode and process information (Lohse & Johnson, 1996), and to infer user intent in real-time interfaces (Goldberg&Schryver, 1995; Jacob, 1991, 1995). However, with notable exceptions (e.g., Goldberg & Kotval, 1998), Eye movements can be recorded by using a wide variety of methods.

1.2 Electrooculograph (EOG) Signals Applications

An electrooculograph (EOG) is a device that measures the voltage between two electrodes placed on the face of a subject so it can detect eye movements. Electrooculography (E.O.G) is a technique for measuring the resting potential of the retina. The resulting signal is called the electrooculogram. Elwin Marg named the electrooculogram in 1951 and Geoffrey Arden (Arden et al. 1962) developed the first clinical application. The main applications are in ophthalmological diagnosis and in recording eye movements.

Table 1. Interfaces used for detecting eye movements

Eye Tracking Technique	Source	Comments
ElectroOculoGraphy (EOG)	Geoffrey Arden (Arden et al. 1962).	This can be manufactured at low price. Installation of electrode is easy, noninvasive. Can be used for long time. Simple and Cost effective
Sclera search coil method	Robinson, 1963;Collewijn, van der Mark & Jansen, 1975	Determined with high accuracy, but needs particular contact lens, Invasiveness to subject is high and experimental time is limited to around 30 min
InfraRedOculoGraphy (IROG)	Kumar&krol, 1992	Head Mounted and Limbus tracking. Special and Temporal resolution will be high but blink is the downside.
VideoOculoGraphy (VOG)	Chan, chang, sang and won, 2006	Non invasive but expensive and large dimension device.

2 EOG in HCI

EOG was used for guiding and controlling a wheelchair for the disabled people (Barea et al, (2002), Tanaka, Matsunaga, & Wang, (2005), Wijesoma et al., (2006)) or for using a virtual keyboard (Usakli & Gurkan, (2010) ;Yamagishi, Hori and Miyakawa, (2006)) and Deng et al. (2010) tested a specific HCI for operating a TV remote control and for a game. Doru Talaba (2012) developed EOG based visual navigation interface HCI (Human Computer Interface) [3-7, 23].

The use of EOG signals as control signal for HMI/HCI plays

a vital role in understanding characterization and classification of eye movements which can be applied to wide range of applications consisting virtual mouse and key board control electric power wheelchairs and industrial assistive robots [14, 20].
The EOG and blinking signals are used in Human-Computer Interfaces in;
The Vehicle Control [Barea et al. (2002); Firoozabadi (2008)], the Video compression driven by eye-interest [Khan & Komogortsev (2004)], the Driver Drowsiness Detection System [Thurn Chia Chieh, Mohd. Marzuki Mustafa, Aini Hussain, Seyed Farshad Hendi (2005)], the ergonomics, the advertisement analysis [Poole & Ball (2005)] the Wearable computers [Bulling et al. (2009)], the Human-Computer-Interactionv(HCI) system (e.g.Virtual keyboard (Usakli et al. (2010)) [11]. The game and operating a TV remote control (Deng et al. (2010)) [12]. The Visual navigation interface (Doru Talaba et al. (2012)).

3 EOG: Data mining aspect

3.1 Time domain features

Based on time domain features like Maximum peak amplitude value (PAV), Maximum Peak amplitude position value (PAP), Maximum valley amplitude value (VAV), Maximum valley amplitude position value (VAP), Areas under curve value (AUC), Number of threshold Crossing value (TCV), variance of EOG Signal (VAR) are extracted in simple non-pattern recognition algorithm by S. Aungsakul et.al (2012) to discriminate eight directional eye movements based on threshold analysis [13, 24]. This work described the useful features in two EOG channels. The combination of features may be useful for the classification of EOG signals. These features can be useful for various advanced HCI applications in future researches mainly in eye-exercise, eye-writing and eye based activity recognitions. This work did not include any classification algorithms, but presented best feature VAP of vertical signal with highest F value (F=1055) followed by AUC of Horizontal signal (F=594.76).

3.2 Feature Extraction

Extract all possible attributes that represent the raw EOG signal to identify the features that contribute more in classification [15-18, 22]. Extraction of features is more important to classification such as characteristics, transforms, structural descriptions or graphs. EOG signal is a widely and successfully used in many clinical applications, such as, evaluation of eye injuries and diagnosis of eye diseases and in many engineering applications, detect activities of human eye. In order to investigate the feasibility of EOG usage for particular task, the extraction of useful features should be done before the classification task. The extraction of EOG signal features is carried out by applying application specific threshold as shown in Figure 1.

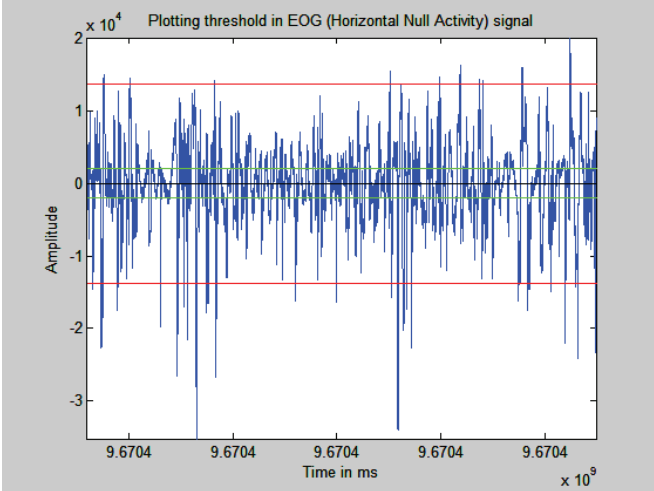

Figure 1. Horizontal EOG (EOGh-during NULL activity)

3.3 Eye movements discrimination

Melodie Vidal, Andreas Bulling, Hans Gellersen (2011) collected naturalistic eye movements and developed a set of basic signal features and discriminated between saccades, smooth pursuits and vestibule ocular reflex movements [8 – 10]. These characteristic eye movements are identified by applying application specific threshold. The features extracted by them are Mean Velocity(raw), Maximum Velocity(raw_, Mean acceleration(raw), Maximum Acceleration(raw), Range of amplitude(raw), Mean Velocity(filtered), Maximum Velocity(filtered), Mean acceleration(filtered), Maximum Acceleration(filtered), Range of amplitude(filtered),slope of the Signal. KNN (K-nearest neighbour) classification on these features discriminated movements and the 80% results showed differentiating saccadic eye movement of normal and epileptic subjects [19,20].
Malini and Subbarao (2011) showed the fourth level approximation coefficient using Haar wavelet can be efficiently used for the analysis of saccadic EOG signal to differentiate between the saccadic eye movement of normal and epileptic subjects. The evaluation indices from the work indicate that wavelet technique used in this study ensures a correct classification rate of more than 98%.

3.3 Classification

The goal of classification is to identify an input pattern with a category or class, which is a set of patterns grouped together based on similarity measures. The similarity depends on the concept of interest: it may be abstract that is detecting all patterns produced by same event or more quantitative that is matching an EOG signal pattern with a prototype. Classification plays an important role in many real time applications. It is important to automate the classification process since hand processing is often not a viable option.
SVM is a margin classifier that draws an optimal hyper plane in the feature vector space; this defines a boundary that maximizes the margin between data samples in two classes, therefore leading to good generalization properties. A key factor in SVM is to use kernels to construct nonlinear decision boundary [21].

4 EOG: Role in Activity Recognition

The aim of this work is activity recognition by eye movements using EOG signals. The research interest in machine interaction recently focuses on recognition of human activity by eye movements. Activity recognition has become a key area of research for HCI. The detection of EOG based different eye movement characteristics features can be used as an alternative to video oculography (VOG). EOG is cheap, light weight, can be used for mobile settings. Three main eye movement characteristics such as saccades, fixations, and blinks – can be robustly detected from EOG signals. These features are able to discriminate between different visual behaviors.

Eye movement analysis using EOG signal play a vital role in recognizing a set of common office activities such as copying a text between two screens, reading a printed paper, taking hand-written notes, watching a video and browsing the web [Bulling et al. 2011]. Using SVM classifier and person-independent training an average precision of 76.1% and recall of 70.5% is obtained in this work.

Eye movements are linked to a number of cognitive processes of visual perception such as visual memory, learning or attention. Eyes are therefore called a window to mind and brain. The cognitive aware systems are able to sense and adapt to a person's cognitive state [Bulling et al. 2011].

We used Andreas Bulling's "recognition of office activities"[1] data set, for EOG signal representation and analysis.

4.1 Performance Analysis

The confusion matrix is a useful tool for analyzing how well the classifier can recognize tuples of different classes. The confusion matrix provides a complete description of any classification results. However the results are usually displayed using indices or factors that describe specific aspects of the classification. A mathematical description of these indices displayed in Table 2. It consist the following classes: Read(R), Write (W), Copy (C), Browse (B), Video (V).

Table 2. Confusion matrix for recognizing activities

	R	W	C	B	V	$\sum$
R	X_{RR}	X_{RW}	X_{RC}	X_{RB}	X_{RV}	O_R
W	X_{WR}	X_{WW}	X_{WH}	X_{WR}	X_{WP}	O_W
C	X_{CR}	X_{CW}	X_{CC}	X_{CR}	X_{CP}	O_C
B	X_{BR}	X_{BW}	X_{BC}	X_{BB}	X_{BP}	O_B
V	X_{VR}	X_{VW}	X_{VC}	X_{VB}	X_{VV}	O_V
$\sum$	A_R	A_W	A_C	A_B	A_V	X_{TOT}

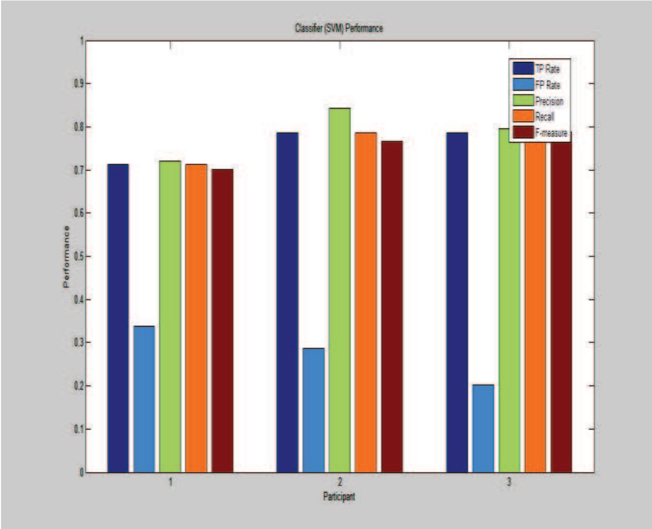

Figure 2 SVM Classifier Performance for activity recognition

The Figure 2 illustrates the performance analysis of EOG signals to recognize activities, in three participants with SVM classifier. The True Positive, Precision for #participant2 is high when compared to other two participants. The false positive is maximum in participant 1.

Grouping Symbols

N is the number of classes I, J Ɛ {R,B,W,V,C}

X_{IJ} is the number of examples of class I classified as J

YI≠J, X_{IJ} are incorrectly classified examples

YI=J, X_{IJ} are correctly classified examples

$O_I = \sum Y_I X_{IJ}$, Total number of examples labeled by the algorithm as class J.

$X_{TOT} = \sum Y_I Y_J X_{IJ} = \sum Y_I O_I = \sum Y_J O_J$

R-Read ; B-Browse; W-Write; V-Video; C-Copy

Performance Measures

Accuracy of I (Acc_I) = $(TP_I+TN_I)/TP_I+TN_I+FP_I+FN_I)$

Sensitivity of I ($Sens_I$) = (TP_I/O_I)

Specificity of I ($Spec_I$)= (TN_I/O_I)

Precision of I ($Prec_I$) = TP/TP+FP

Relevant Factors

True positives of I (TP_I) = X_{II}

True negatives of I (TN_I) = $X_{TOT}-O_I-A_J+X_{II}$

False positive of I (FP_I) = A_I-X_{II}

False negative of I (FN_I) = O_I-XII

[1] www.andreas-bulling.de/datasets/recognition-of-office-activities/

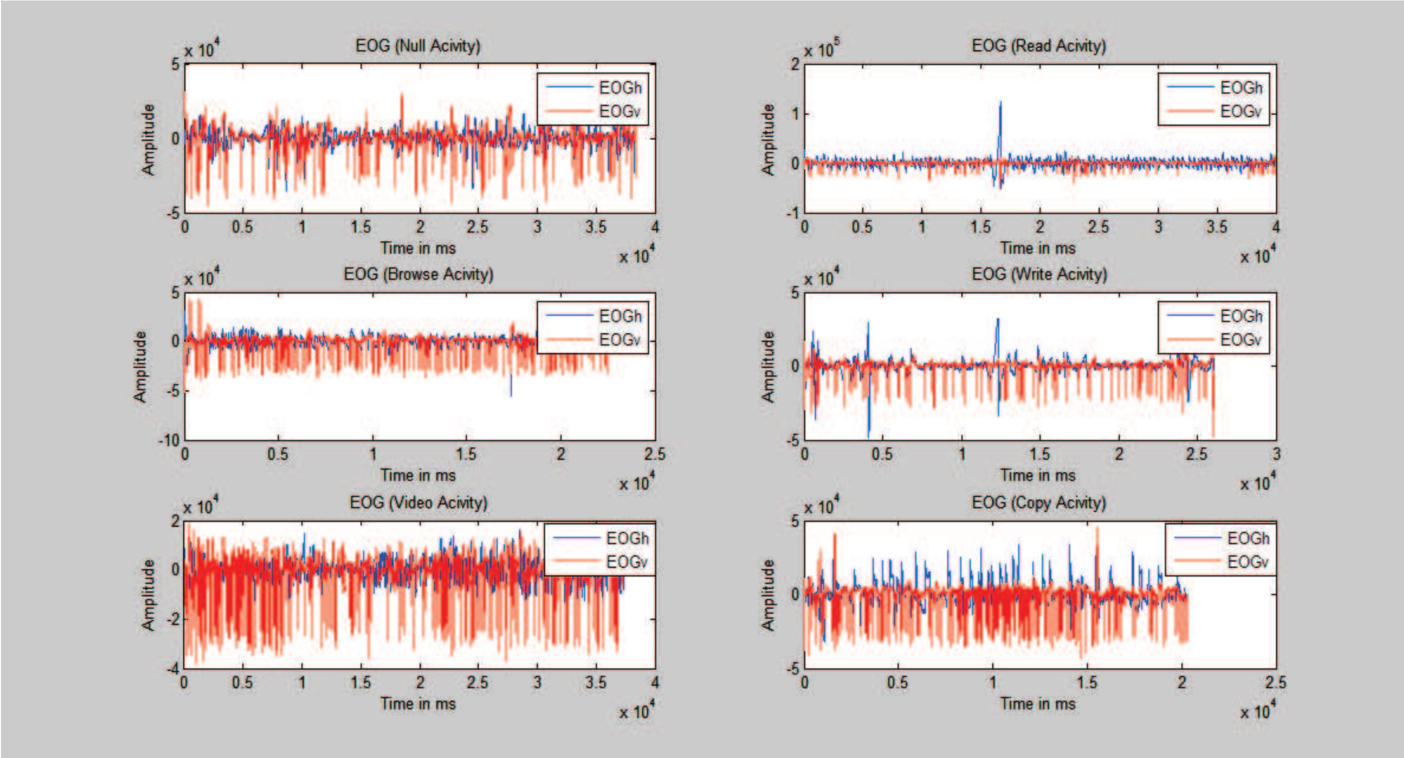

Figure 3. EOG Signal (Horizontal, Vertical) in various activities

5 Results and discussion

Figure 3 demonstrates various activities using eye movements by EOG can be portrayed as a regular pattern by a specific sequence of saccades and short fixations of similar duration. The amplitude change in signals varies for various activities which can be used in identifying the regular office activities. The reading activity using EOG is pattern by small saccades and fixations. No large change in amplitude included in reading. This is due to small eye movement between the words and fast eye movement between ends of previous line, beginning of next line. Writing was similar to reading, yet required greater fixation duration and greater variance. It was best described using average fixation duration. Copying activity includes normal back and forth eye movements which involves saccades between screens. This was reflected in the selection of small and large horizontal saccade features, as well as variance in horizontal EOG fixations. In contrast, watching a video and browsing are highly unstructured. These activities depend on the video or website being viewed. These results propose that for tasks that involve a known set of specific activity classes, recognition can be streamlined by only choosing eye movement features known to best describe these classes.

6 Conclusion

This finding supports EOG as a simple measurement technique for capturing eye movement characteristics that reflect activity. EOG can be used as an alternative to video-based eye tracking. EOG is particularly suited for mobile settings as it is cheap, only requires light-weight signal processing. Three of the main eye movement characteristics, saccades, fixations, and blinks –detected from EOG signals able to discriminate between different activities. This may lead to further advances in EOG signal processing, eye movement analysis, eye movement based activity recognition, and eye-based interaction. Precise ground truth annotation is an open issue in eye movement based activity recognition. As the eyes move constantly, fast, the eye movement annotation is particularly challenging and only subtle at times. In this work, issues with annotation were not explicitly addressed. Instead, these issues could only be minimized by focusing.

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