IJCTA, 8(3), 2015, pp. 1209-1216

Performance Evaluation of EOG based HCI Application using Power Spectral Density based Features

Sandra D'Souza[1] and N. Sriraam[2]

Abstract: Interestingly, in recent years active research is going on in the area of signal processing using Electrooculography signals (EOG). The reason behind this lies in the fact that the eye signal remains intact even though most of the body parts fail to function normally. In this context, the eye movements can be used to interact with the computers, hence leading to the need for human computer interface (HCI) development. This paper considers four basic tasks like blinking, reading, eyes closed and open for task based classification. Here, horizontal and vertical EOG signals derived from a group of healthy volunteers are considered. Power spectral density (psd) based features are extracted and are used to classify the four basic tasks. As a pilot study, k nearest neighbor (kNN classifier) and linear discriminant analysis (LDA) has been used. The results indicate that the highest classification accuracy is obtained using Yule Walker's estimation for vertical EOG. Also, performance of the kNN using three nearest neighbors stands out the best possibility with the classification accuracy of 81.87%. Also, the results rule out the possibility of using linear discriminant analysis for the task based classification using EOG signals.

Keywords: Electrooculography; tasks; power spectral density; classifiers

1. INTRODUCTION

Human body is made up of several functional units. Every system, for example, nervous system or cardiovascular system or any other system is as important as every other system. Each system employs different physiological processes in it and these physiological processes are quantified by bio signals. Bio signals are measured and monitored for various reasons [1]. Clinically they are helpful in evaluating the diseases and dysfunctions of systems. Another important area where the bio-signals are used is to develop assistive devices for rehabilitation. Bio-signals like Electroencephalogram (EEG), Electrocardiogram (ECG) have been used to develop human computer interfaces for the disabled and quadriplegic. However, in recent times the biopotential of the eye known as Electrooculogram (EOG) has gained popularity. The human eye has a potential between cornea and retina, with cornea having positive polarity and retina with negative polarity. It was in 1848, Emil du Bois-Reymond observed that the retina is electrically negative with respect to the cornea. Literature study reveals that this electric potential is typically within the limit of 0.4-1.0 mV. Electrooculography is a non-invasive technique to measure the electric potential changes caused by eye movements. The recorded signal is called Electro-oculogram (EOG). The EOG is produced by the static electric polarization of the eye [1]. The potential changes that are caused by the movement of the eye are measured by placing electrodes around the eyes. In progressive neurodegenerative diseases like Lou Gehrig's disease (Amyotrophic Lateral Sclerosis) the brain and spinal cord nerve cells are affected but the eye movements remain intact [2]. Also, the fact that moving eyes requires very small amount of

1 Department of Instrumentation & Control Engineering, M.I.T, Manipal, Karnataka, India.
Email: Sandra.dsouza@manipal.edu
2 Centre for Medical Electronics & Computing, M.S. Ramaiah Institute of Technology, Bangalore, Karnataka, India.

energy, in comparison with the energy used up for other gestures, has encouraged the use of eye movement signals for developing human computer interfaces or rehabilitation systems based on eye movement signals [3]. There are several methods for acquiring eye movements; however, Electrooculography is a method that is preferred well due to its simplicity in usage, minimal discomfort to the subject and suitability for long time monitoring. In addition to its traditional use in clinical and laboratory use, there is tremendous increase in interest towards EOG based research as it can be used for human computer interaction and assistive devices.

With the growth of Human-Computer Interaction, the automated systems are becoming important. As the biomedical data is extremely complex, its manual analysis is difficult. The sampling rates for processing of biomedical signals normally ranges from 100 Hz to 10 - 20 kHz. Hence automated systems for analysis of biomedical data are very important [4]. Though human being is highly skilled and quick in analysis of visual patterns, he is slow in calculations and exhausting computations. Also, physical factors like tiredness, boredom etc. affect the analysis. Human analysis most of the time becomes subjective and qualitative. Quantitative analysis is possible using computers. Obviously, inter-observer and intra observer errors are common in human analysis. Automated analysis overcomes all the limitations of human observer.

The raw signal does not provide any useful data for automation. Hence it is required to extract time domain or frequency domain features from the acquired EOG signal [7-8]. It is found during the study that all extracted features do not significantly contribute in the process of automation. Hence the selection of suitable features from the raw EOG and selection of appropriate classifier are of prime significance. Combining signal processing with soft computing systems has encouraged automated data analysis.

The main objective of this pilot study is to identify suitable features and classifiers for task based classification using EOG. The power spectral density based features using Yule walkers and Burg's estimation have been extracted from the EOG signals obtained for different tasks and are used as input to the kNN classifiers with different number of nearest neighbors considered and also discriminant analysis is performed.

2. METHODS AND MATERIALS

2.1 EOG Data Set

The potential difference that occurs due to the horizontal movement of the eyes can be recorded by electrodes placed on the canthi, and vertical movements can be recorded by placing electrodes just above and below eyes. On the forehead, a reference electrode is placed. A potential difference is noted when the eye rotates to the right or left or up and down. The electrode placement is shown in Fig 1 [4].

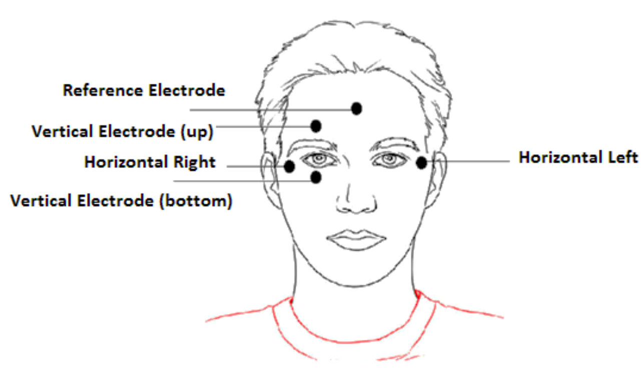

Figure 1: Placement of electrodes

The major components of EOG lies in the frequency range of DC to 30Hz. Pre-amplification and filtering of EOG signals is done. A notch filter with cutoff of 50Hz is used to suppress the interference caused by the powerline. The useful frequency band is selected by using a pass band of 0.05Hz and 30Hz [5]. The EOG data recording is done under constant background illumination. We have considered EOG recordings of 20 male and 20 female volunteers, chosen in the age group of 16 to 52, with mean 32.8 and standard deviation 10.7. The parameter consideration of the volunteers is given in table 1. The recording is done considering the following activities: initial no specific activity (NC), eyes closed (EC), blinking (EB), reading (ER) a selected passage [5]. Fig 2 indicates the duration of each activity. The experiments were conducted and recordings were obtained at the laboratory of Instrumentation & Control engineering department of the institute.

Table 1

Parameter Table

Parameter	*Value*
Number of subjects	40
Average_age (years)	32.825
BMI (kg/m^2)	18.5-25
Average Height (m)	1.66
Average Weight (Kg)	55±2.5

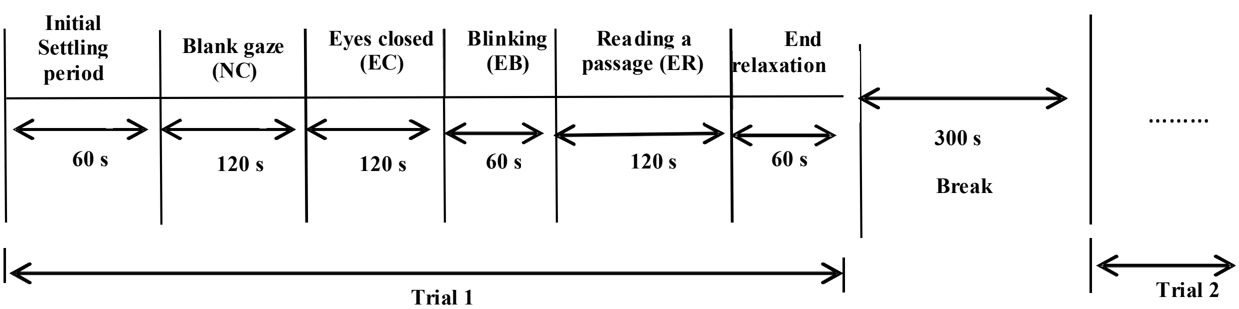

Figure 2: Timing Diagram of activity duration

2.2 Feature Extraction

Many biological signals show many hidden useful properties which are not revealed in their raw form. Hence to include a thorough analysis of any biological signal, it is necessary to extract features from the signal. The feature extracted can be time domain or frequency domain or time-frequency features. However, the features thus selected should be able to represent the original signal without losing the importance of the signal [6]. Power spectral density (psd) based features have been useful in several cases. Hence in this research work we have investigated the use of the power spectral density based features extracted using autoregressive (AR) Burg's and Yule walker's estimation methods [7] [8]. After obtaining the AR coefficients, a_k, and variance, psd is computed using parametric method as in (1)

$$S(f) = \frac{\sigma_p^2 T}{\left| \sum_{k=0}^{p} a_k e^{-j2\pi kT} \right|^2} \qquad (1)$$

By plotting the features, a variation of coefficients was observed in all the activities considered. Fig. (3) and Fig.(4) show the power spectral density plots for horizontal and vertical EOG respectively.

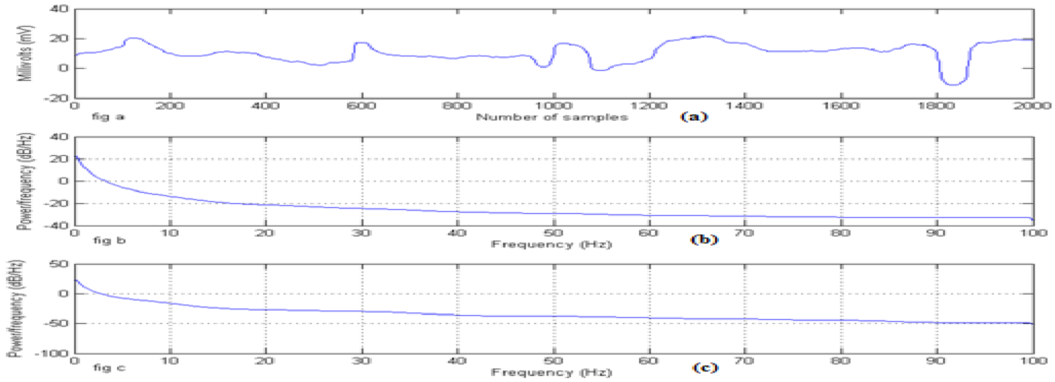

Figure 3: (a)The Horizontal EOG (b) Yule walker estimate (c)Burg estimate

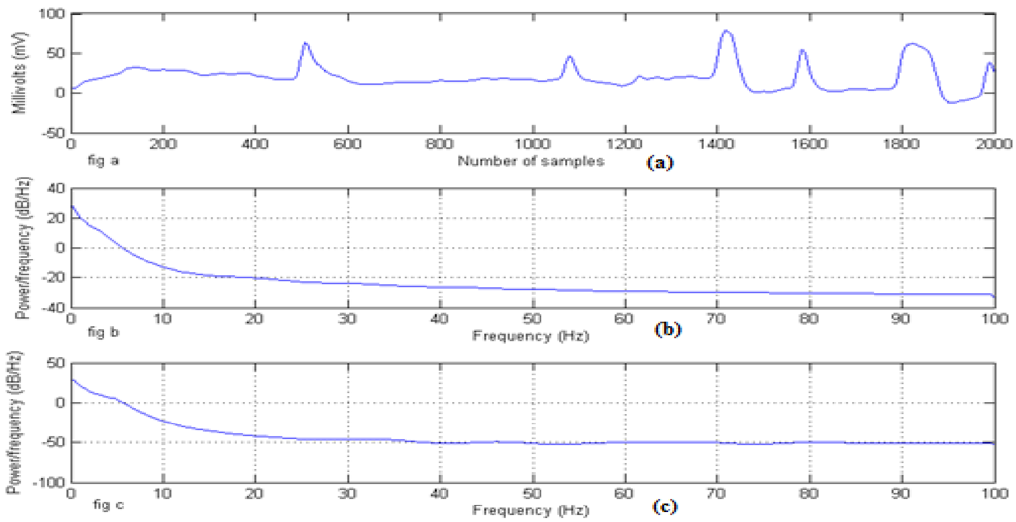

Figure 4: (a)The Vertical EOG (b) Yule walker estimate (c) Burg estimate

Fig. 5 shows the variation of the power spectral density based features for horizontal and vertical EOG respectively. The data set is divided into overlapping segments and 150 features have been extracted for each segment. Fig 5(a) shows the power spectral features extracted for horizontal EOG and 5(b) for vertical EOG.

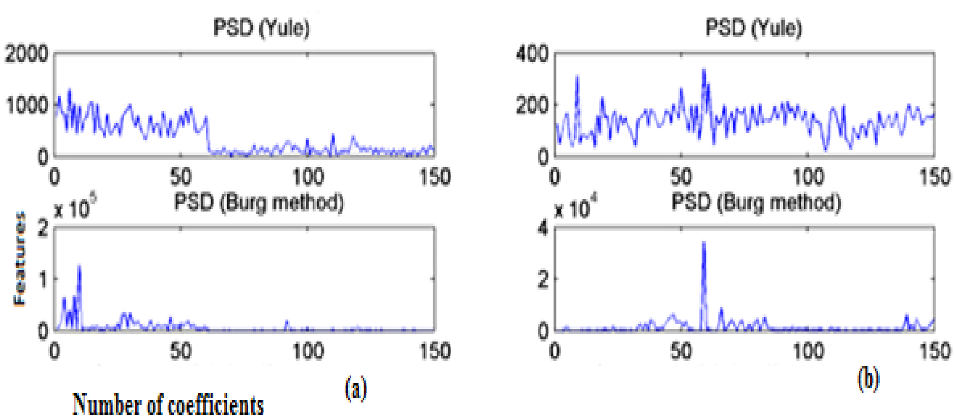

Figure 5: (a) Horizontal EOG (b) Vertical EOG

2.3 CLASSIFICATION

Several papers have demonstrated the use of artificial neural networks for classification of Electrooculogram signals [9-10]. In the literature [11-17], a number of efforts have been made for developing human computer interfaces using Electrooculogram signals. In this work, we have considered EOG data set for task based classification. Estimation of the discriminant function parameters is done using the set of features as the training set. The boundary between the two classes is determined by discriminant functions. Linear method of discriminant analysis is used. K nearest neighbor (kNN) classifier uses nearest neighbor algorithm for classification. The distance of the test data pattern to all the training data patterns is calculated. The class of training data pattern that gives the shortest distance is the class of the testing pattern. This method is much simpler as there no explicit training takes place here. The distance metric used is Euclidean distance measure. The distance is calculated using the equation (2).

$$d(u, v) = \sqrt{\sum_{i=1}^{s} (u_i - v_i)^2} \tag{2}$$

Where s is the number of features, u and v represent the points.

The power spectrum can be estimated using several methods [6,18]. The methods considered in this research work are the approaches like the Yule-Walker, the Burg. In the proposed work we have extracted features from both horizontal and vertical EOG, for all the different activities that are considered in figure 2. A variation of coefficients was observed in all the activities considered.

3. PERFORMANCE EVALUATION

The performance evaluation of different classifiers is presented in table 2. The data considered is acquired at the sampling rate 200 samples per second which means the data has 12000 samples per minute.

Table 2

Performance Of the Classifiers

Classification method	*Performance Evaluation*	*psd_Burg_H*	*psd_Burg_V*	*psd_Yule_H*	*psd_Yule_V*
K nearest neighbor (kNN) k=3	Classification Accuracy(%)	75.0	78.13	78.75	81.87
	Sensitivity (%)	65.00	87.50	72.50	82.50
	Specificity (%)	93.33	87.50	94.17	95.83
K nearest neighbor (kNN) k=4	Classification Accuracy(%)	64.38	64.38	65.63	65.63
	Sensitivity (%)	67.50	80.00	62.5	67.5
	Specificity (%)	89.17	77.50	90.0	90.83
K nearest neighbor (kNN) k=5	Classification Accuracy(%)	58.13	60.00	62.50	63.12
	Sensitivity (%)	70.0	75.00	67.50	60.0
	Specificity (%)	87.50	77.50	85.83	90.0
K nearest neighbor (kNN) k=6	Classification Accuracy(%)	56.87	60.0	62.5	63.12
	Sensitivity (%)	60.0	80.0	62.5	60.0
	Specificity (%)	86.67	79.17	85.83	90.0
Linear Discriminant analysis (LDA)	Classification Accuracy(%)	31.25	21.25	21.25	31.25
	Sensitivity (%)	25.0	25	27.5	35.0
	Specificity (%)	80.0	80	75.83	77.50

The data set of 2 minutes each for reading, eyes open and eyes closed has been considered and 1 minute recording of blinking activity is considered. 150 features per segment extracted from the segmented data have been used for the study.

The results show that the best performance is recorded by kNN classifier with k=3 while LDA records least performance. Critical observation of the tabulated reading infers that the power spectral density using Yule Walker's method has highest classification for vertical EOG. Figure 6 shows the comparison of different classifier performance. Figure 7 shows the performance comparison of kNN with number of neighbors 3 with linear discriminant analysis results.

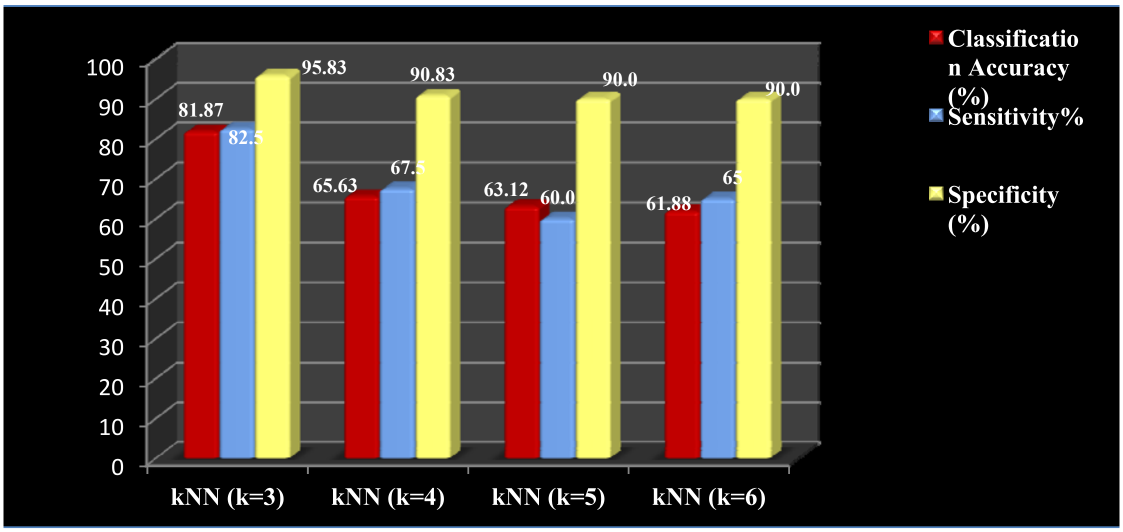

Figure 6: Comparison of kNN classifier performance

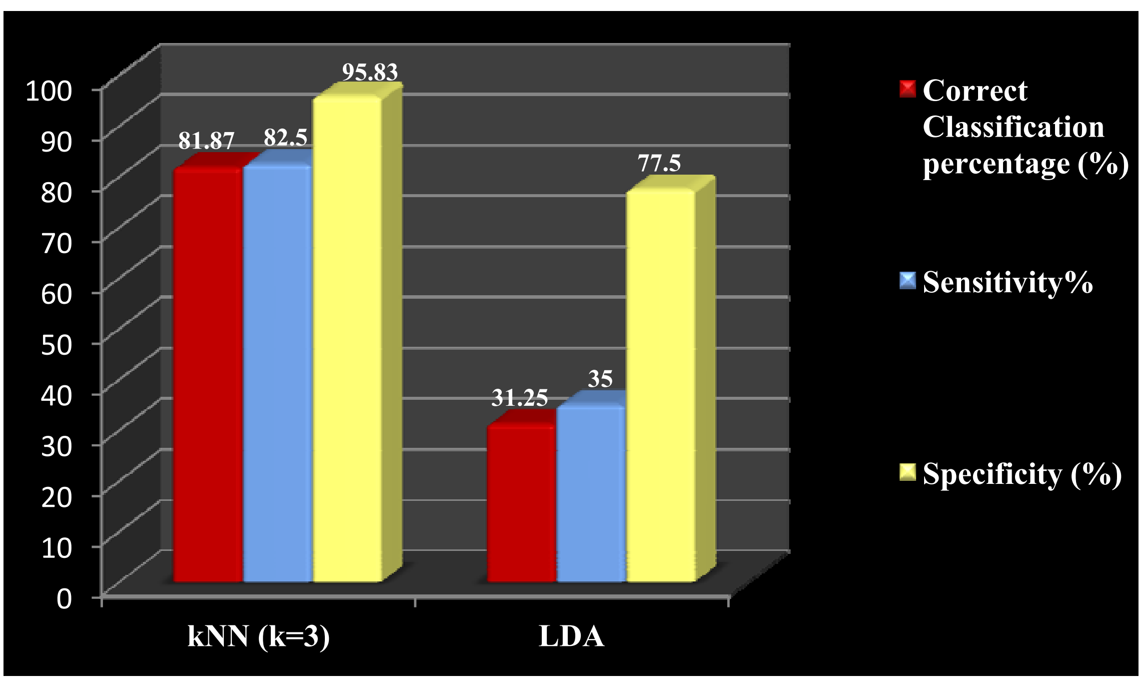

Figure 7: Comparison of kNN (k=3) and LDA performance

4. CONCLUSION

A pilot study of investigation of a suitable classifier for task based classification is done. The experimental results have been presented. The results have shown that kNN with k=3 has performed the best. Also, it is observed that the linear discriminant analysis is not a suitable choice for task based classification using power spectral features of EOG signal. This study has developed the foundation for more sophisticated EOG signal classification wherein a combination of optimal features and classifier would be found. The results suggest an investigation into a nonlinear classifier for task based classification. HCI systems can be controlled using the selected classification method for EOG signals. The study is conducted as a foundation for development of HCI systems for use of persons with severely impaired motor activity. In such persons, the eye signal remains intact in spite of the severe disability.

ACKNOWLEDGEMENTS

We acknowledge the cooperation of the volunteers and the administrative support.

References

[1] Malmivuo, J., & Plonsey, R. “Bio-electromagnetism: Principles and applications of bioelectric and bio magnetic fields”, Oxford University Press, New York 1995, Ch. 9 & 28.

[2] McDermott, CJ; Shaw, PJ (22 March 2008). “Diagnosis and management of motor neurone disease” *BMJ* (Clinical research ed.) 336 (7645): 658–62.

[3] Barea, R., Boquete, L., Mazo, M., & Lopez, E., “System for assisted mobility using eye movements based on Electrooculography”, *IEEE Transactions on Neural Systems and Rehabilitation Engineering*, 2002,10(4), 209–218.

[4] Sandra D’Souza, N.Sriraam, “Design of EOG signal acquisition system using virtual instrumentation-a cost effective approach”, *International Journal of measurement Technologies and Instrumentation Engineering*, vol.4, 2014.

[5] Sandra D’Souza, N.Sriraam, “Statistical Based Analysis of Electrooculogram Signals: A Pilot Study”, *International Journal of Biomedical and Clinical Engineering*, 2013,2(1), 12-25.

[6] Semmlow John L., “Biosignal and Biomedical Image Processing MATLAB Based Applications”, 2004, Marcel Dekker, Inc.

[7] Rangaraj M. Rangayyan, “Biomedical Signal Analysis”, 2nd Edition, ISBN: 978-0-470-91139-6 Wiley-IEEE Press.

[8] R. Palaniappan, *Introduction to biological signal analysis*, 2010,Ventus Publishing.

[9] Aysegul Guven, Sadik Kara, “Classification of Electrooculoram signals using artificial neural networks”, *Expert systems with applications*; 2006, pp.199-205.

[10] R. Barea, L. Boquete, M. Mazo, E. Lopez, and L. M. Bergasa, “EOG guidance of a wheelchair using neural networks”, Proceedings of 15th International Conference on Pattern Recognition, 2000, volume 4, pp. 668-671.

[11] Shang-Lin Wu, Lun-De Liao, Shao-Wei Lu, Wei-Ling Jiang, Shi-An Chen, Chin-Teng Lin, “Controlling a Human–Computer Interface System With a Novel Classification Method that Uses Electrooculography Signals”, *IEEE Transactions on Biomedical Engineering*, vol 60 (8), pp. 2133–2141, Aug. 2013.

[12] English, E., Hung, A, Kesten, E, LaTulipe, D.; Zhanpeng Jin “EyePhone: A mobile EOG-based Human-Computer Interface for assistive healthcare”, 6th International IEEE/EMBS Conference on Neural Engineering (NER), pp. 105-108, Nov. 2013.

[13] Paul, G.M, Fan Cao, Torah, R, Kai Yang, Beeby, S, Tudor, J., “A Smart Textile Based Facial EMG and EOG Computer Interface”, *IEEE Sensors Journal*, vol 14(2), 393 - 400, Feb 2014.

[14] Merino, M., Rivera, O., Gomez, I Molina, A., Dorronzoro, E., “A Method of EOG Signal Processing to Detect the Direction of Eye Movements”, First International Conference on Sensor Device Technologies and applications, July 2010, pp. 100-105.

[15] Andreas Bulling, Jamie A. Ward, Hans Gellersen, and Gerhard Troster, "Eye Movement Analysis for Activity recognition Using Electrooculography", *IEEE transactions on pattern analysis and machine Intelligence*, vol 33,(4),2011.

[16] Harry Septanto, Ary Setijadi Prihatmanto, Adi Indrayanto, "A Computer Cursor Controlled by Eye Movements and Voluntary Eye Winks Using A Single Channel EOG", International Conference on Electrical Engineering and Informatics, August 2009, Selangor, Malaysia.

[17] Shang-Lin Wu, Lun-De Liao, Shao-Wei Lu, Wei-Ling Jiang, Shi-An Chen, Chin-Teng Lin, " Controlling a Human–Computer Interface System With a Novel Classification Method that Uses Electrooculography Signals", *IEEE Transactions on Biomedical Engineering*, 60 (8), pp. 2133-2141, Aug. 2013.

[18] D.C. Reddy, Biomedical signal processing, *Principles and Techniques*, 2005, Tata McGraw-Hill.