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Detection of Reading Movement from EOG Signals

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Abstract*— In this paper, it is aimed to analysis of Electrooculography (EOG) signals recorded during the back to eye movement (retrieving words/re-reading) and skipping lines while reading. Two situations are characterized by large amplitude fluctuations in EOG signals. For this aim, EOG signals were recorded simultaneously while reading a text from 10 volunteers and changes in EOG signals caused by jumping a bottom line and back movements as reading were analyzed. The classification of these signals may allow the development of a new method for early and rapid diagnosis of various reading disorders (for example dyslexia). This study consists of two main processes; feature extraction and classification. Firstly, two features were determined from the recorded EOG signals for determination of retrieving words/re-reading from EOG signal. Then these signals were applied as input to various classifiers. The classifier performances were evaluated by calculating accuracy, sensitivity, specificity, precision and F measure. Overall classification results were obtained with high performance from all classifiers, and the highest accuracy of the classifiers used was 98% for each of the Random Forest and k-NN classifiers. The results show that this proposed method has an important performance for classification of eye movements from EOG signals.

Keywords—, Electrooculography, classification, biomedical signal processing, eye movements

I. Introduction

Electrooculography (EOG) signals have recently been widely used in human computer interaction (HCI) applications. Because it is easy to record and is a non-invasive method, EOG signals have become a suitable signal for HCl applications.

EOG is a method of measuring the potential difference between the anterior pole and posterior pole of the eye [1]. The magnitude of the EOG signals indicates how far the eyes jumping in a reference position[2]. Studies have shown that there is a linear relationship between eye movement and EOG amplitude up to a certain degree [3]. The EOG signal is recorded noninvasively using surface electrodes placed in the region surrounding the eye. In generally, the amplitude of the EOG signal; it is between 0.05 mV-3.5 mV per degree of eyeball movement in the range of 0.1 to 15 Hz. [3, 4].

During reading of a text, the eye moves from left to right, which changes the amplitude of the EOG signal. For example, when someone starts reading a text from the beginning of the line (left side) and reach the end of the line (right side), positive amplitude occurs in the EOG signal since positive electrode is placed around the right eye. When eye is jumping the bottom line, a negative amplitude is formed as a sudden amplitude change. Fig. 1 shows EOG signal of while a volunteer is reading a text.

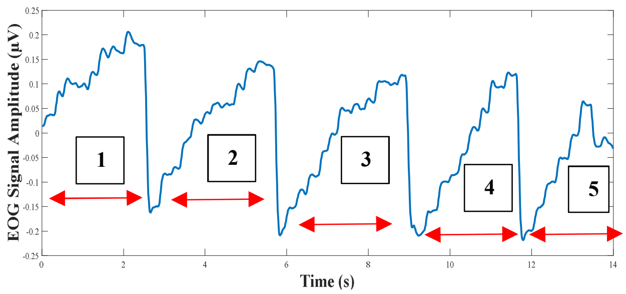

Fig. 1. EOG signal that recorded during reading of five lines of a text.

In literature, there are studies on the classification of eye movements from EOG signals. Upward and downward directions, left and right directions, clockwise and counterclockwise, and the Z movement are the eye movements like blink and gaze were detected in these studies [1,4-6].

Hande et al. [4]proposed a new intelligent detection model based on EOG signals. In this study an artificial neural network was used for definition of eye movements. In addition to the literature studies, this study also included the perception of tics and the blinking of the eye. The features extracted from the EOG signals were used as input for a feedforward artificial neural network. It is obtained 94.19% accuracy as a result of the study.

Banerjee et al.[5] designed a human-computer interface system to detect different types of eye movements (straight, up, down, right, left and blink) using k-NN and feedforward neural network classifiers. They used automatic regression parameters, Power Spectral Density (PSD) and wavelet coefficients.

Aungskan et al.[6] obtained the first derivative technique using EOG signals proposed a human computer interface system. This system detected eight different eye movements

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using a classification algorithm consisting of threshold classification, initial analysis, and feature extraction. The proposed method achieved 100% accuracy for three-subject tests.

Banerjee et al. [1] recorded an EOG signal for a period of five days from normal subjects. Hjorth parameters were extracted from the signals. These features were classified using the Bagging Ensemble classifier. The maximum classification accuracy as 83.09%, 90.27%, 80.75% and 92.27% was obtained.

It has been discussed in the literature that EOG signals has been analyzed in the detection and diagnosis of various diseases. Latifoğlu et al.[7] used EOG signals to detect diagnosis of attention-deficit hyperactivity disorder disease, Waldthaler et al.[8] used EOG signals to evaluate Parkinson's disease.

As seen in the literature studies, important results have been obtained by analyzing of EOG signals with detection of eye movement direction. The main contribution of the proposed study is to determine the EOG peaks occurring with back to eye movement (retrieving words/re-reading) and skipping lines while reading for detection of some reading disorders like dyslexia.

Involuntary reading back depends on the type of text being readable. But subjects having various reading problem such as dyslexia suffer from involuntary reading back regardless of the type of text being readable. [9, 10]. Usually reading back is resulted with reading disorder and occurs involuntarily [11]. The rate of reading back is higher in individuals with dyslexia compared to healthy individuals [9]. This study aims to classify the eye movements that occur reading a text using from EOG signals. Eye movements has been defined as skipping lines that occurs when the jumping bottom line while reading the text and retrieving words/re-reading that occurs when it is returned the previous words during reading the text.

With the successful classification of these two eye movements from EOG signals, diagnosing various reading disorders such as Dyslexia can be performed with a new approach. To the best of our knowledge, there is no such study in the literature.

II. MATERIAL AND METHOD

The recorded EOG signals were filtered before processing of signals. Flowchart of the study was shown in Fig. 2.

A. EOG Data Acquisition System

The EOG signals were recorded from two channels at 100 Hz sampling frequency using BIOPAC MP36 data acquisition system. The first channel was recorded to obtain horizontal eye movements and the second channel was recorded to obtain vertical eye movements.

Electrode placements were given in Fig. 3. The EOG signal is acquired on 6 Ag-AgCl disposable electrodes, two for horizontal channel, two for vertical channel and two for reference.

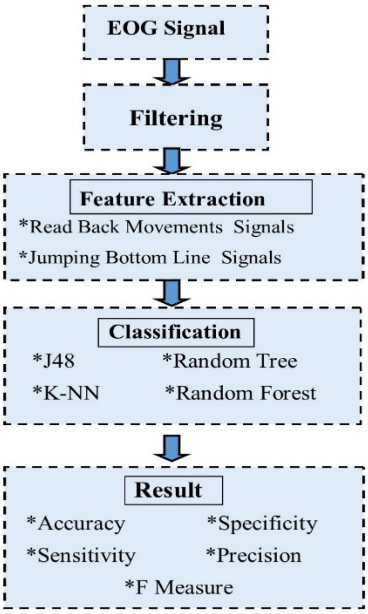

Fig. 2. Flow chart of the study

The recorded signals were obtained from 10 volunteers (5 female and 5 male) who are between 8 and 12 years old. The Human Researches Ethics Committee of Erciyes University endorsed its approval for the study.

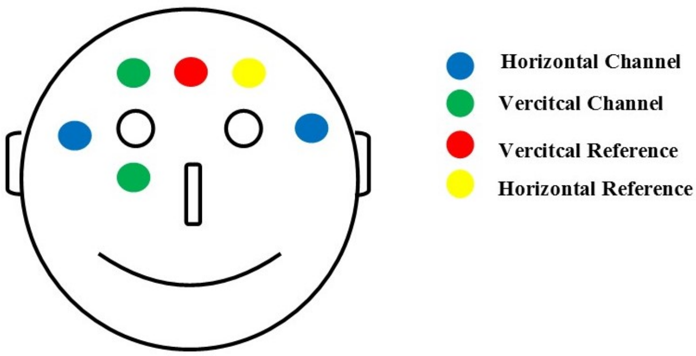

Fig. 3- Placement of Electrodes

B. Experimental Setup

The participants read a 12-point Times New Roman font text written with Turkish language (native language for each participants) consisting of five lines as seen in Figure 4 and EOG signals were recorded simultaneously.

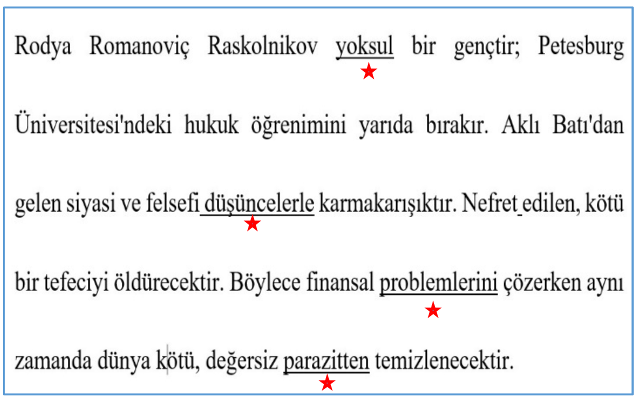

Fig.4. Text and marked points

We marked four different words in the reading text, and it was instructed to participants return to the marked point when they reached the end of the line. Thus, we obtained reading back pattern from the recorded EOG signals. In the following sections, these signals will be referred as retrieving words/re-reading signals. In addition, the jumping a bottom line when reading the text, we obtained the skipping line signals. These signals are characterized by large amplitude fluctuations.

C. Filtering

The raw EOG signals were filtered before feature extraction in order to get EOG signal in the frequency range of 0.1 to 15 Hz [5]. Because it is observed that the maximum information is placed with this frequency range. The EOG signals were filtered using 4th Butterworth band pass filter in the specific frequency range.

D. Feature Extraction

As mentioned in the recording procedure (*B*), reading back signals with 100 sample length and jumping bottom line signals with 100 sample length from the filtered EOG signals were obtained. These two features were selected manually because the reading back and bottom line movements were performed experimentally. These features were used as input to various classifiers that will be discussed in the next section. Figure 5 shows that reading back signals from the filtered EOG signal. This recorded signal contains 4 reading back signals marked with red line.

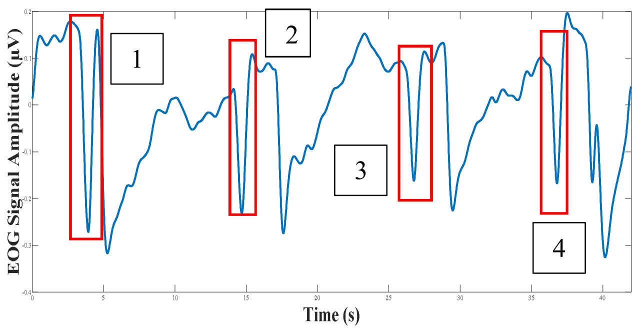

Fig. 5. Obtained Read Back Signals

Fig. 6 shows skipping line signals from filtered EOG signals. Fig. 6 shows the 4 number of moving to bottom line signals. Read back and moving to bottom line from EOG signals recorded from 10 volunteers were extracted as feature.

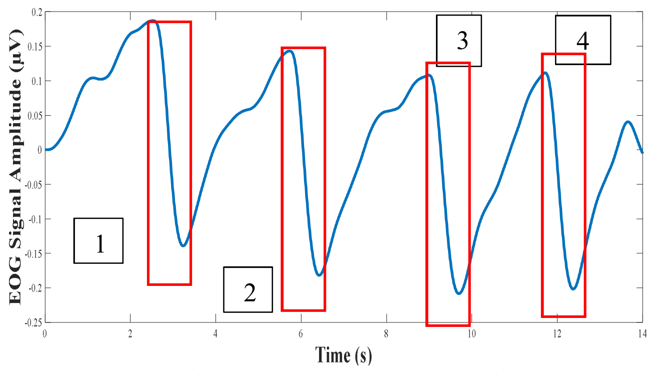

Fig. 6. Obtained Jumping Bottom Line Signals

III. RESULTS

WEKA program was used for classification algorithms. WEKA (Waikato Environment for Knowledge Analysis) is an open-source-code Data Mining application. 100 sample length the reading back signals and 100 sample length the moving to bottom line signals were applied to the classifier as input. It has been determined the classification performance of the reading back signals and skipping line signals for each classifiers. The results were shown in Fig.9. In this study, we used four different classification algorithms, J48, Random Forest, Random Tree, k-NN (K-Nearest Neighbor). Also, 5-fold cross validation, 10-fold cross validation and leave one out cross validation train were tried and similar performance results were obtained for the three train methods. Therefore, only 10-fold cross validation results were given in this study. In 10-fold cross validation data was randomly partitioned into 10 folds and the system was trained with 9 of the folds and testing was performed on the left-out fold. So, 90% of the data is used for training and the remaining 10% for testing.

In the k-NN algorithm, an unknown sample in a prediction set is classified according to the majority of the neighbors closest to it in the training set. Since this algorithm will determine the neighbors closest to a given point, the distance between that point and all other points will be calculated and processed one by one. The J48 classifier is an implementation of the C4.5 decision tree algorithm developed by Quinalan. J48 is a decision tree algorithm generally used for the classification of nonlinear and small data[12]. Decision trees are becoming powerful and popular tools for classification for medical research[13-15].

Random forest is a supervised learning algorithm which is used for both classification as well as regression. Random Forest Algorithm is one of the best classification algorithms developed by Leo Breiman and Adele Cutler for the classification of big data[12]. It creates decision trees on data samples and then gets the prediction from each of them and finally selects the best solution by means of voting. It is an ensemble method which is better than a single decision tree because it reduces the over-fitting by averaging the result[16].

Sensitivity and specificity are generally used as the performance criteria of classifiers in medical research[17]. Accuracy is defined as the ratio of correctly classified samples to the total number of samples. Sensitivity is the number of positive samples correctly classified and indicates the classifier's ability to correctly classify the positive class. Specificity indicates the measure of negative samples classified as negative. Sensitivity is a measure of how many specimens classified as positive are truly positive. Indicates how much a positive classification of a negative class can be avoided [18]. The F-score is a typical dual classification criterion that can be interpreted as a weighted mean and sensitivity mean [18]. The higher the F value, the more successful models can be obtained. These parameters are calculated by the following equations;

$$Accuracy = \frac{(TP+TN)}{TP+TN+FN+FP} \quad (1)$$

$$Sensitivity(Recall) = \frac{TP}{TP+FN} \quad (2)$$

$$Specificity = \frac{TN}{TN+FN} \quad (3)$$

$$Precision = \frac{TP}{TP+FP} \quad (4)$$

$$F\ Measure = 2 \times (\frac{(Precision \times Recall)}{(Precision + Recall)}) \quad (5)$$

As shown in Table I, the accuracy rates of J48, Random Forest, Random Tree and k-NN classifiers are 92%, 98%, 90%, 98%, respectively. Random Forest and k-NN classifiers have the highest classifier accuracy with 98 %accuracy rate. Among the classifiers used, the lowest accuracy rate belong to the Random Tree classifier. When the other parameters of the classifiers are evaluated, the highest sensitivity, precision and F measure values also belong to Random Forest classifier. According to the classifier results, it was concluded that Random Forest classifier gave better performance than other classifiers in classifying the features obtained from EOG signals.

IV. CONCLUSION

EOG signals are one of the most popular signals recently used in human computer interaction (HCI) applications[19, 20]. As it is easy to record and is a non-invasive method, EOG signals have become a suitable signal for HCl applications. In addition, EOG signals are one of the simplest methods for tracking eye movements. Because of advantage of being easy to implement, EOG signals can be used to detect eye problems.

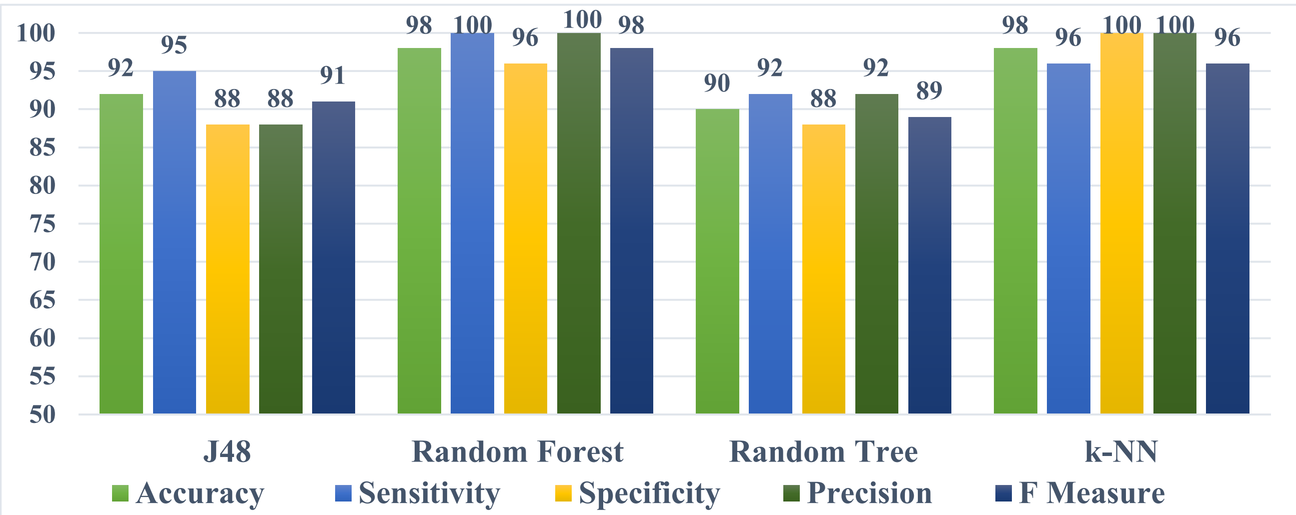

Fig. 9. Classification results

This study proposes a method for classifying of EOG signals in cases of reading back and skipping line causing large fluctuations in EOG signals when reading a text. The features obtained from the EOG signals recorded by our proposed recording procedure were applied to the J48, Random Forest, Random Tree and k-NN classifiers as input. Classifier performances were evaluated by calculating accuracy, sensitivity, specificity, precision, F measure parameters.

As shown in Fig. 9, Random Forest and k-NN classifiers have the highest classifier accuracy. The lowest classifier accuracy was obtained in Random Tree classifier. When the classifier performances were evaluated in general, high accuracy rate was obtained with all classifiers.

The reason for using EOG signals in this study is that directional eye movements can be detected with the help of EOG. The obtained results show that the experimentally generated eye back movements can be detected with high accuracy using EOG signals.

To the best of our knowledge, there are no studies in the literature classifying back movement and skipping line signals during reading a text from EOG signals. Therefore, this study contributes to EOG literature. In addition, these results show that the features obtained from EOG signals can be used to classify two different movements (read back movement and jumping bottom line).

As the number of re-reading increases while reading a text, reading time of the text will increase. Determining the read back movement, number of re-reading and reading time parameters can be important in the evaluation of reading disorders such as dyslexia and hyperlexia. In this study, the obtained results show that, it can be detected the number of re-reading from EOG signals. In the future studies, EOG signals recorded from various disease groups can be analyzed using proposed method.

In this study, two features re-reading and skipping line were selected semi automatically. Also reading back movement and moving to bottom line signals were obtained experimentally using recording scenario. In the future studies, we are planning to carry out studies on modeling and detection of these two features automatically.

As a result of this study, EOG signals were classified with 98% success for determination of re-reading and skipping line. The classification of EOG these signals may allow the development of a new method for early and rapid diagnosis of various reading disorders (for example; dyslexia and hyperlexia). The results can be basis for future studies.

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