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An Overview of Classification of Electrooculography (EOG) Signals by Machine Learning Methods

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Abstract

The distribution of the studies conducted between 2011-2021 in the fields of (Electrooculography) EOG and eye movements, EOG and wheelchair, EOG and eye angle, EOG and sleep state, EOG and emotion estimation and EOG and game application was determined according to years, and the most cited studies were examined and presented. The study areas are listed as Eye Movement Classification, Wheelchair, Sleep state, Eye Angle, Emotion State and Game Applications from the most to the least number of articles. When we examine in terms of the number of citations, they are listed as Sleeping state, Eye Movement Classification, Wheelchair, Eye Angle, Emotion State and Game Applications, from the most to the least. In these studies, it has been tried to make the lives of people who have become disabled in various ways better by using the brain-computer interface with machine learning.

1. INTRODUCTION

Electrooculography (EOG) measures voltage fluctuations caused by eye movement. EOG can be used to monitor the direction users are looking by taking advantage of signal changes. EOG also conveys highly recognizable information from the eyelid movement known as staring and blinking [1]. Small Electrooculography (EOG) instruments have very good temporal resolution. The amplifiers measure the electric field generated by the resting potential in the corneo-retinal region through two skin electrodes placed just next to the eyes [2].

Studies in this area include EOG and eye movements [1-4], EOG and wheelchair [5-8], EOG and eye angle [9-10], EOG and sleep state [11-14], EOG and emotion prediction [15-19] and EOG and game exercise [20-23]. A hybrid writing system [1] combining visual feedback technology on eye movements with usually EEG and EOG signals [1], a grading method used in a wireless EOG-based HCI device to detect eye movements in eight directions [4], five office-based activities EAR's feasibility (copying text, reading written paper, manually taking notes, watching videos and browsing the Web) and participants' rest periods (EMPTY classroom) were carried out [3].

In this study, studies on EOG and Machine learning, Eye movement classification, Wheelchair control, Eye angle, Sleep state, Emotion estimation and Game application were searched in IEEE (Institute of Electrical and Electronics Engineers) between 2011-2021. The most cited studies on the subjects mentioned in our study are presented.

2. METHODS

The literature review was carried out in two stages. In the first stage, a search was made in the IEEE database related to EOG and machine learning between 2011-2021. The articles obtained as a result of this search

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are also classified under six main headings. These six main headings are respectively; Eye movement classification, Wheelchair control, Eye angle, Sleep state, Emotion estimation and Game application and 51 articles were reached.

In the second stage, these titles, EOG and six main titles were combined one by one and a second search was made in the IEEE database. The numerical distribution of these searches related to EOG and machine learning by years was obtained and the most cited articles were selected for each topic.

2.1. Classification of EOG And Eye Movements

As a result of the scanning, the eye movement studies in the last ten years are given in Figure 1.

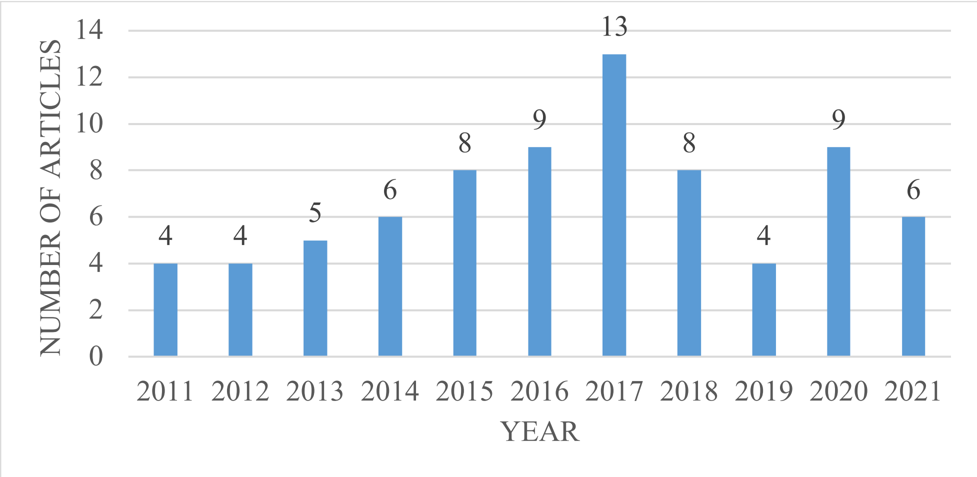

***Figure 1.** Distribution of studies in the field of EOG and eye movement classification by years*

Twenty healthy subjects, twelve males and eight females, aged 24-32 years were recruited. None of these subjects had psychiatric, neurological, or other disease records. This research is the first to aim an EEG-EOG hybrid BCI writing system that uses the visually-informed classification result and actively selects the target letter. In the EEG-EOG hybrid BCI writing system, a brain-based sorting point is presented for the related feature to inform the subject about the prediction of the system. If the continued classification is correct, the subject has successfully selected the target letter with a simple gesture, a wink that is particularly appropriate for our situation. This paradigm is called row-column seen feedback (RC-VF). In this system, the average sorting accuracy and information transfer rate (ITR) of 20 individuals were 97.6% and 39.6% (±13.2) [bit/min]. In this study, baseline fix and ERP feature extraction were applied. The sorting result is found based on the LDA classifier previously estimated from the training dataset. The model code was developed using the Psychophysics Toolbox (http://psychtoolbox.com) and OpenBMI and Matlab [1].

The experiment was carried out with eight healthy people aged between 22-25. This study consists of three parts. First, it is the pre-test section that calibrates the classification parameters of the measurement system used in the study to determine the eye movements of each user, according to the users. Secondly, the training section on the EOG system (Eight aspects were considered in this system, each of which was tested ten times) and third, ten times for each direction (look up, look down, look left, look right, look up-left, look down-left, look up-right, and look down-right). While the highest accuracy value was 86.25%, the average classification accuracy of eight users was found to be 88.59% [4].

Three eye movement features (saccades, fixations, and blinks) were determined to detect eye movement analysis using an electrooculography (EOG) system. This method defines algorithms to detect eye movement feature and evaluates repetitive eye movements. Using the support vector machine (SVM) classifier, an average of 76.1% accuracy and 70.5% recall was achieved between unrelated (let alone one person) classes and participants. MATLAB and C were used throughout the study [3].

Eye movements were recorded with three participants, two men and one woman, for the evaluation of saccade detection. Saccades are rapid eye movements made when the image rotates from one object to another. Electrooculography (EOG) was used to follow these movements. It was investigated whether saccadic suppression of image displacement (SSID) could be used in the virtual environment (VE) to unconsciously rotate and flip the viewpoint. Matlab and Psychtoolbox were used for stimulus presentation [2].

2.2. EOG and Wheelchair Control

As a result of the scanning, the wheelchair control studies in the last ten years are given in Figure 2.

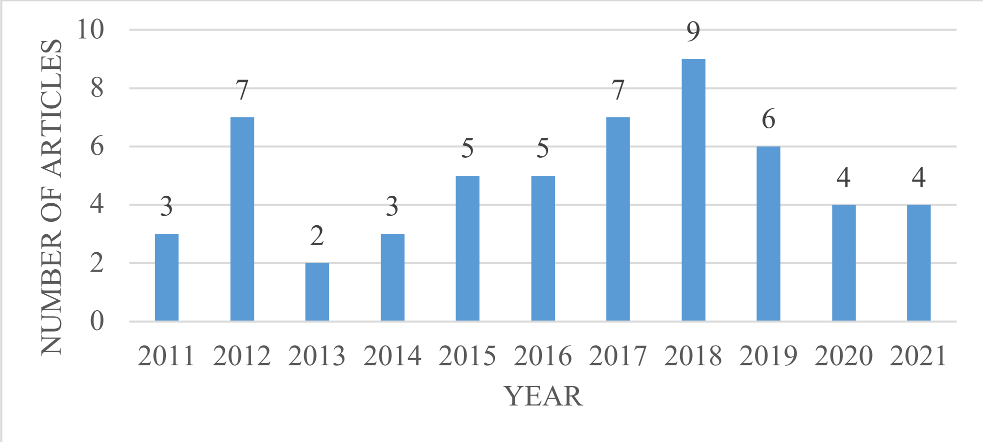

Figure 2. *Distribution of studies in the field of EOG and wheelchair by years*

A new electrooculogram (EOG) based HMI has been proposed for wheelchair control. One synchronous and two asynchronous experiments were performed on four (S1-S4) healthy men aged 24-26 years with normal eye movements. Three trials were performed for each individual on three different days. This experiment was created to compare the presented HMI with EOG-based human-machine interfaces (HMI) and thus to prove that the presented HMI can be used to effectively control the wheelchair in the outdoor environment [2].

Asynchronous electrooculography (EOG)-based HMI is presented to assist patients with advanced spinal cord injury. The presented HMI aims to enable patients to interact with blinking in a smart home environment (lots of electrical devices and smart wheelchairs) [8].

Developed an EOG signal acquisition system to improve the lives of people with disabilities. The EOG signals were then classified to generate control signals from these signals (depending on the amplitude and duration of the signals) for the movement of the wheelchair prototype. Amplifiers have been developed to capture left-right eye movements and up-down eye movements from the eye [5].

Electroencephalography (EEG)-based and Electrooculography (EOG)-based, using neural networks, and a wheelchair that can control eye movements have been presented to measure neural activity in the brain and eye for quadriplegia patients [7].

2.3. EOG and Eye Angle

As a result of the scanning, the eye angle studies in the last ten years are given in Figure 3.

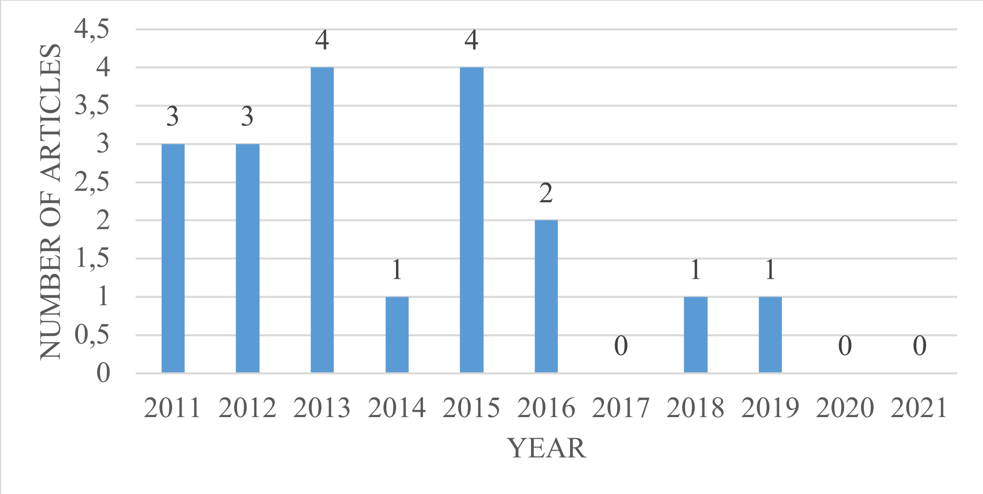

Figure 3. *Distribution of studies in the field of EOG and eye angle by years*

A prototype named PANTOJO was developed. This prototype functions as a situation machine that detects and classifies eye movements according to saccades. Transitions in eye positions at multiples of 5° from +40° to -40° were detected with a 75% success rate. With a transport delay of 100 ms, an update rate of 46 Hz and an accuracy of 2.5°, the PANTOJO has proven to be a versatile point of view tracker in many trials such as communication devices for the disabled (eg tetraparesis), gait research or driving analysis [9] .

A system using eye movement recognition EOG-based methods and Learning Vector Quantization algorithm is proposed to provide a means of communication for people who have lost limb functions and speech abilities. In this study, eye-rolling movements such as up-down turn, left turn, right turn, blink and left turn, up-right turn, left-down turn, down turn (angle of the diagonal) are introduced. API (application programming interface) was used to control icon movements based on demo results. First, it is decided to measure the EOG signals at 1.8 second intervals, secondly to decide whether eye movement continues in the 1.8 second EOG data, and to subtract the data of each movement from the 1.8 second EOG data, if any. Third, the Fast Fourier Transform was used for the frequency properties of the extracted motions. Fourth, the Learning Vector Quantification network and the characteristics of the EOG features in each movement were used to recognize eye movements. The average recognition accuracy of eye movements was found to be around 95% [10].

2.4. EOG and Sleep Status

As a result of the scanning, the sleep status studies in the last ten years are given in Figure 4.

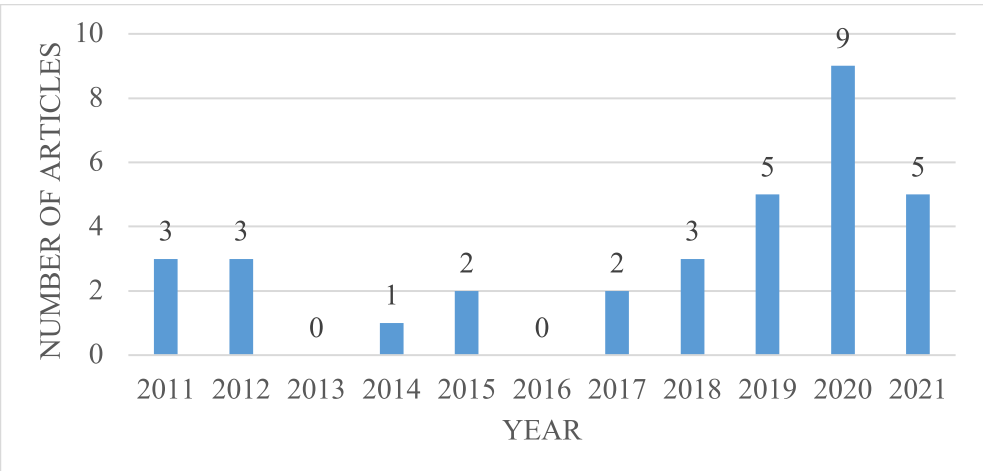

Figure 4. *Distribution of studies in the field of EOG and sleep status by years*

Grading of sleep stages is an examination used in the diagnosis of sleep disorders. Presented the first deep learning approach for sleep stages grading and temporal content of each 30 second data window, using all multivariate and multimodal polysomnography (PSG) signals (EEG, EMG, and EOG) without calculating spectrograms or excluding artifacts. The data used in the tests is the public MASS dataset session 3. In this model, it is compared with alternative automated approaches based on convolutional networks or decision trees [14].

A deep learning model called Deep Sleep Network has been proposed for automatic scoring of sleep stages based on single-channel raw EEG. In this model, evaluation was made using different single-channel EEGs (F4-EOG (left), Fpz-Cz and Pz-Oz) in two sleep datasets (AASM= American Academy of Sleep Medicine and R&K) with different characteristics and scoring standards. Looking at the results, MASS = Montreal Archives of Sleep Studies: 86.2-81.7%, Sleep-EDF: 82.0-76.9%, and using the latest methods MASS: 85.9-80.5%, Sleep-EDF: both data generally achieved accuracy in the set and a macro F1 score of 78.9-73.7% [13].

In order to prevent traffic accidents due to loss of attention and drowsiness in drivers, a study was designed to detect drowsiness and fatigue while driving and to warn the driver by monitoring physiological signals. In this study, the amount of information about drowsiness obtained from the signals obtained from the electroencephalogram (EEG), electrooculogram (EOG) and electrocardiogram (ECG) during the driving test was tried to be maximized with a simulation. The quality of the features was made with datasets collected from 31 drivers in the simulation test. Results Classification accuracy of 95-97% was achieved with an average of 31 drivers, demonstrating the importance of FMIWPT (Fuzzy MI-based Wavelet-Packet Algorithm) in identifying features that correlate well with different dormancy states [11].

A study was designed to assist physicians in the diagnosis and treatment of people with sleep disorders. This research is based on different EEG datasets from PhysioNet, which uses the Sleep-EDF database developed and presented by the researchers to distinguish sleep periods. This research was supported by an SVM (vector machine) to recognize the state of sleep stages and determine whether the received signal belongs to the sleep stage or the waking stage [12].

2.5. EOG and Emotion

As a result of the scanning, the emotion studies in the last ten years are given in Figure 5.

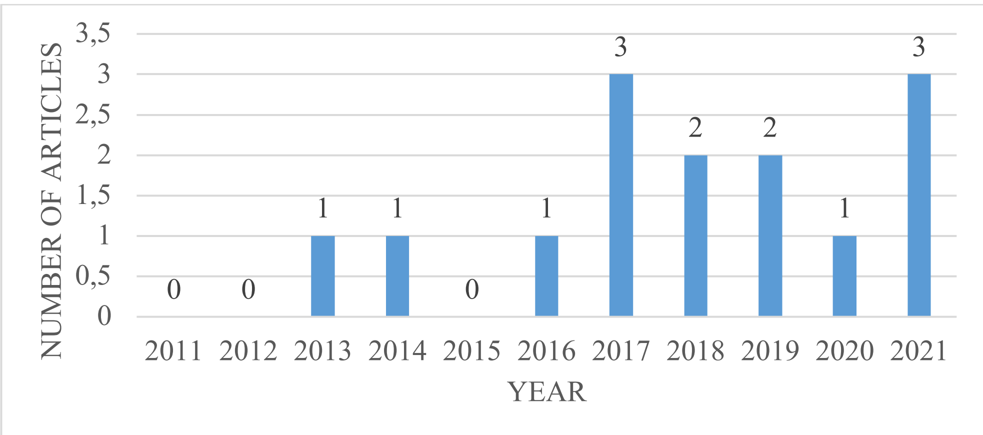

Figure 5. *Distribution of studies in the field of EOG and emotion by years*

A human-computer interactive application is designed using Electroencephalogram (EEG), Electromyogram (EMG), Electrooculography (EOG) and other physiological signals to study human emotional state based on Deep Belief Network (DBN). This study was carried out in DEAP database with valence, arousal and dominance classes and comparative evaluation. The accuracy of these data (Value, arousal and dominance) was found to be 78.28%, 70.33% and 70.16%, respectively. The DEAP database was used to verify the effectiveness of the Deep Belief Networks classifier [17].

An emotion recognition system based on machine learning techniques is proposed, which is a physiological response to the analyzed multimodal signal sources (EEG, EOG, plethysmograph, EMG, GSR, Respiratory belt and Temperature). This study established a new method for emotion regression by mapping physiological signals to Fisher Score space based on HMMs [15].

A classification has been proposed that combines methods of using biological signal sources to detect emotional states, the strengths and emerging challenges of these methods, and detection of facial expressions by EMG, saccade detection using Electrooculography (EOG). Four basic expressions (neutral, sad, happy and angry) were used in the classification [18].

Physiological signals (DEAP) were used for emotion analysis. Emotion arousal experiments were conducted by showing 32 subjects to watch several videos activating sensory states such as valence, arousal, and dominance in the DEAP database [16].

A system that can detect human emotions with EOG signals has been created. This system aims to recognize emotion with human eye movements. In the classification, outcomes that emerged as happy, pleasant, fearful, sad and angry were used [19].

2.6. EOG and Game App

As a result of the scanning, the game app studies in the last ten years are given in Figure 6.

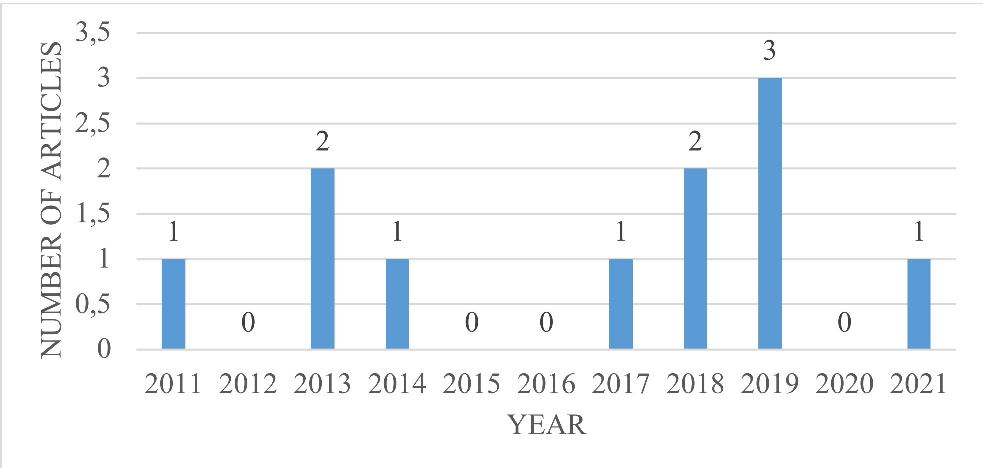

Figure 6. *Distribution of studies in the field of EOG and game applications by years*

Baseball game control with nine eye movements (still, up, down, left, right, up-left, down-left, up-right and down-right) and blink signal, EOG signal, eye movement detection and HCl depending on signal processing A study was carried out to achieve this with the system. The characteristics of these nine eye movements were created and according to them, the accuracy rate of the EOG signals was passed to the stage, and this rate was 100% in the 3rd round and 92% in the 5th round [20].

A correction technique is designed to avoid the effects of misclassification in EOG signals with eight-way eye movement (look up, look down, look right, look left, look right-up, look right-down, look left, and look left-down). In this research, the correction technique to learn eye movements was applied to the HCI baseball game. A Matlab-based application was used for the analysis of EOG signals [23].

Thanks to a system that can detect both EEG and EOG signals, a signal processing system has been designed, which has 9 directional controls (still, up, down, left, right, up left, down-left, up-right and down-right) that control eye movements via EOG and one direction control via EEG. This system can be used comfortably in daily life, as EEG-based BCIs can provide communication between the brain and other devices. The lowest accuracy rates were 94%, the highest 100% [21].

In the study, in which a 38-year-old healthy man was used as a subject, it was determined whether the EOG could be extracted from the EEG and whether the resulting signal was related to the eyes. They used ocular artifacts (EOG) in the EEG signal to control eye states. In the first experiment, the end positions of the eyes were analyzed in the horizontal (left, right), vertical (top, bottom) and neutral (center) directions. Horizontal eye movements were correctly classified in 87% (right) and 94% (left), vertical 92% (up) and 91% (down) [22].

3. RESULTS AND DISCUSSION

While the most work was done in the field of eye movement classification, the least work was done in the field of game applications. Recently, a significant increase has been observed in the number of studies in the field of eye movements. However, the studies in the field of sleep state, which ranked third in terms of the number of studies, were the most cited studies. Article rankings were made as Eye Movement Classification, Wheelchair, Sleep status, Eye Angle, Mood status and Game Applications. When we examine in terms of the number of citations, these are Sleep status, Eye Movement Classification, Wheelchair, Eye Angle, Mood State and Game Applications in order from largest to smallest.

Researches in these fields of study consist of studies to make life easier for people who cannot use their limbs as a result of accident or who have diseases such as paralysis. Many studies have been carried out so that people who are confined to a wheelchair can continue their vital activities without the help of another person. In addition, studies on sleep status constitute important studies in the prevention of accidents with sleep status classification, especially in cases where drivers are sleepless for a long time. Studies on sleep state are the most cited studies. With these efforts, people who become in need of care as a result of various accidents or diseases will be helped to continue their lives without the need for another person.

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