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High Precision Eye Tracking Based on Electrooculography (EOG) Signal Using Artificial Neural Network (ANN) for Smart Technology Application

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***Abstract*— Electrooculography (EOG) signal is the potential difference between the cornea and the retina of the eye. The voltage amplitude changes when the eye moves in various directions. This change produces a distinct EOG pattern when the eye moves in a particular direction. Therefore, by monitoring the EOG signal, it is possible to track the eye movement. The EOG based eye-tracking technique can be extended to maneuver smart wheelchairs for neurodegenerative disease patients. For a successful operation of such a smart wheelchair, an accurate classification of the EOG signal is required. In this experimental study, we collected two channel EOG signals in the laboratory from multiple individuals and propose an Artificial Neural Network (ANN) based method to differentiate among the nine classes of EOG signals: up, down, left, right, down-left, down-right, up-left, up-right, and blink. This wide range classification would be suitable to perform complicated tasks in smart technology platform. Our model can successfully predict the eye movement from the statistical properties and dominant frequency of the measured EOG signal with an accuracy, precision, recall, and F1 score of 99%. This is a significant improvement over past studies conducted by various researchers for the same purpose and to the knowledge of the authors, such a high accuracy has not been previously achieved for the nine classes of EOG signals mentioned earlier. The proposed model is compatible for real-time smart applications based on eye movements.**

Keywords— EOG, Eye tracking, ANN, Smart technology, Smart wheelchair.

I. INTRODUCTION

As time progresses, human beings are becoming more dependent upon modern technology, like smart phones, computers for communication, etc.

Patients with neurodegenerative conditions like Huntington's, Parkinson's and Alzheimer's disease, which result in the death of nerve cells in the brain, are conscious and cognizant but unable to move or speak. In some serious cases, patients require the assistance of a smart wheelchair for mobility [1].To develop a communication device which has the best interfacing method for this kind of smart wheelchair and easy to use for neurodegenerative disease patients, eye tracking interfacing method using EOG (electrooculography) signals with machine learning has the most potential [2]–[6].

An Electrooculogram (EOG) is a signal generated from rapid eye movement between fixation points. The amplitude of the signal is the potential variation between the cornea and the retina of the eye. The voltage measured between the cornea and retina in between 0.05 to 3.5 mV with a frequency range of about 0.15 to 30 Hz. Since this potential does not shift in response to eye movement, it can be thought of as a stable electrical dipole with a negative pole at the fundus and a positive pole at the cornea. Because of the steady state potential of an EOG, surface electrodes are placed to the left and right of the eye to measure eye position using the steady dipole. When the individual looks straight ahead, the output is zero, and the steady dipole is symmetrically positioned between the two electrodes. Looking to the left brings the positive cornea closer to the left electrode as a consequence of which a measurable voltage is generated.

Machine learning (ML) is a branch of Artificial intelligence (AI) that employs analytical methods to develop a system for analyzing data by learning from it, identifying patterns, and making predictions with minimal human intervention. The input data can be in form of numbers, picture or words etc. and ML uses these forms of data to create a mathematical model for the prediction as accurate as possible.

The aim of this experimental study is to use ML to correctly distinguish among nine possible eye movements: blink, up, down, left, right, down left, down right, up left and up right. This wide range classification would be suitable to perform complicated tasks in smart technology platform. After collecting two channel EOG potentials from multiple individuals in the laboratory, we extracted several statistical properties of the signal and its dominant frequency. Using these parameters, we designed an Artificial Neural Network (ANN) to classify the EOG signals. The proposed model is compatible for real-time smart applications.

II. RELATED WORK

A lot of works are already done for developing technology that can use the eyes as a controller. According to a scientific report, a study used a method where EOG signal allows a person to regulate a wheelchair. By using classified EOG signals, the user can guide the wheelchair to move right, left, forward, and stop [2].

On PC systems, there has also been the use of ML to identify EOG signals. After preprocessing the EOG signal, Dong et al. used discrete wavelet transform to investigate left,

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right, up and down motion [3]. They were fruitful in their endeavor to identify the signals with 96.11% average accuracy using the support vector machine (SVM) algorithm.

Another experiment used EOG signals and machining learning to detect only blink events [4]. The aim was to avoid computer vision syndrome (CVS). To count the number of blinks, a discrete wavelet transform and quadratic kernel SVM were used, and they were accurate in 95.83% of cases [4].

Bulling et al. developed an EOG-based application for distinguishing fixations, saccades, and blinks using 62-90 features from a continuous wavelet transform, such as mean, variance, and maximum value [5]. SVM was used to achieve 76.1% accuracy in stimulating interest in eye ball related behavior recognition (EAR).

In another study, three machine learning algorithms, K-nearest neighbor (KNN), SVM and Decision Tree (DT) were applied to classify six classes of EOG signal with an accuracy of 96.9%, 96.8% and 95.4% respectively [6].

III. Methodology

This research is separated in different segments and a flow chart of the overall wok of this research has shown in Fig 1.

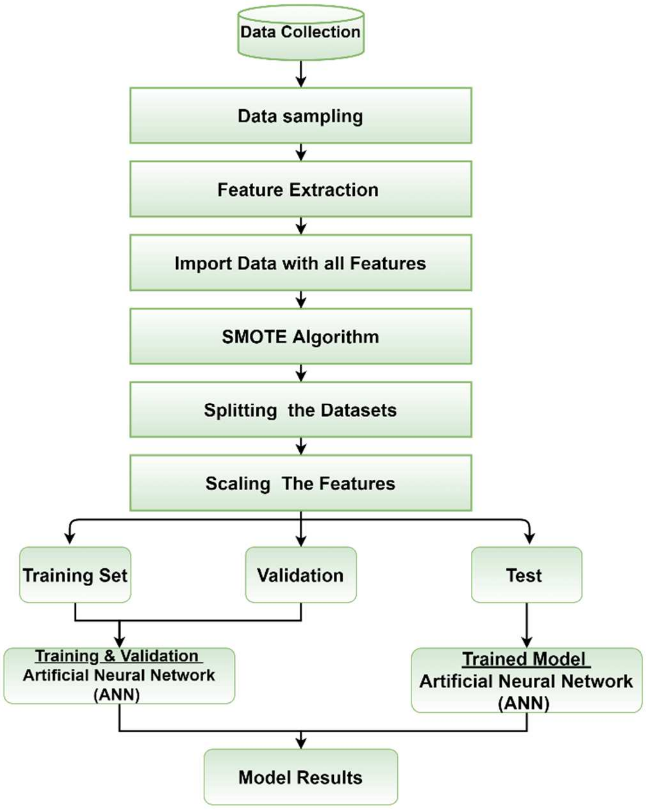

Fig. 1. The flow chart of this study.

A. Data Collection

In this research, it was necessary to collect data of nine directional EOG eye signals of blink, up, down, left, right, down left, down-right, up left, and up-right. So, all these EOG signals were taken from 20 individuals where 10 individuals were male and 10 individuals were female, and a total of 450 samples. Data was collected from the KUET biomedical laboratory using the Biopac MP3X data acquisition system. For each endeavor, the most significant component is the equipment. For successful experimental research, high-quality equipment is always required. The following is a list of the various equipment needed for this work project- 1) Electrolyte Gel, 2) Disposable Electrodes, 3) Electrode Lead Cables, 4) Connection Cables, 5) Power transformer, 6) BIOPAC MP3X Acquisition Unit, 7) Desktop, 8) Power Cable, 9) LED, 10) Connecting Wires, 11) Arduino Board, 12) Battery- 9V, and 13) Buzzer.

This experiment used a navigation setup to collect data on ocular movement in all directions. To prepare the setup, nine LEDs are placed on a worksheet, one in the center, four in each corner, two in the top and down middle positions, and two in the left and right side middle positions. The worksheet is 70cm by 96cm in length and width. The Arduino system is used to control all of the LEDs. 1200ms is the time it takes for the LED illumination to transfer from the center point to the other LED places. When the subject closed his/her eyes for a blink, it was impossible for the subject to follow the light. So we set up a buzzer to acquaint the subject when to close his/her eyes and when to open his/her eyes to directly concentrate toward the center LED light. And the difference between the two beeps of the buzzer was 1200ms. To obtain accurate EOG data, the navigation setup was kept 50cm distant from the subject's eye. Figure 2 showed the experimental setup for this research.

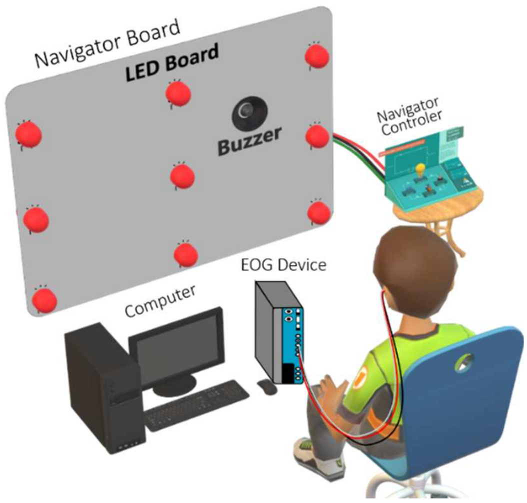

Fig. 2. Experimental setup for this work

Data is gathered using six disposable electrodes. Electrode lead wires link the electrodes to the Biopac MP3X Acquisition Unit. Two electrodes are utilized for the horizontal channel, two electrodes are used for the vertical channel, and the remaining two electrodes are used as reference electrodes. To gather and analyze data, the acquisition unit is connected to the desktop using a USB connection. In Fig. 3, the placement position of electrodes is shown and the sampling frequency was 125 Hz.

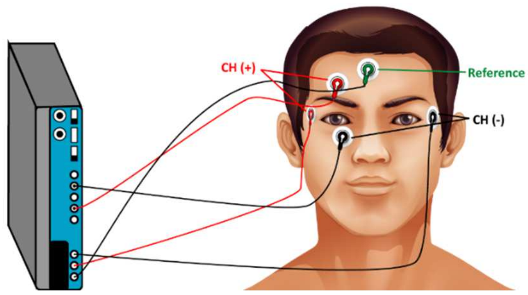

Fig. 3. Electrodes placement on the subject.

Electrodes are one of the most important pieces of equipment for the experiment. The positioning of the electrodes is critical for a successful experiment and obtaining EOG data. For EOG, the Biopac MP3X Acquisition unit has two channels: horizontal and vertical. Two electrodes are implanted on the temporal bone (squamous) on both sides of the skull to measure horizontal (left-right) eye movement. One electrode is put on the supraorbital or superciliary ridge for vertical (up-down) eye movement and the other on the infraorbital foramen for horizontal (side-to-side) eye movement. As a reference electrode, two electrodes are employed. The parietal bone of the skull receives one. This experiment requires all eight basic eye movements, as well as a blink of the eye. 15 trials are taken from each person for each eye movement. One set of trials (15 trials) takes 20 seconds to complete.

B. Features Extraction

From each EOG signal sample, there were two channels of data, one for eye movement in the right direction and another for movement of the left eye. So, in this work, the EOG data comes from 20 individuals. There were 9 different types of eye movements and so far, the subjects have provided a total of 450 samples. we calculated 7 attributes for each eye side movement. Altogether there were 14 features from every single sample.

In our study, we used raw data. There were some difficulties in using raw data that's why before analyzing the data, we used a function called detrend. So, detrend is a process where Your data is detrended by subtracting the mean or a best-fit line (in the least-squares sense). Detrend treats each data column separately if your data has several data columns. By removing a trend from the data, it is easy to concentrate the study on the oscillations in the trend's data. A linear trend usually suggests that the data is increasing or decreasing consistently.

After the process of detrending the raw data, we calculated seven attributes which considered for analyzing the EOG signal. Maximum and minimum value of the samples are two of them and the rest are :

1) Mean value: For a random variable vector A made up of N scalar observations, the mean is defined as

$$Mean = \frac{1}{N}\sum_{i=0}^{N} A \qquad 1$$

2) Standard deviation: The standard deviation is a measure- ment of a set of values' variation or dispersion. A low standard deviation implies that the values are close to the set's mean, whereas a high standard deviation shows that the values are dispersed across a larger range. So, for a random variable vector A made up of N scalar observations, the standard deviation is defined as

$$SD = \sqrt{\frac{1}{N-1}\sum_{i=0}^{N} |A_i - Mean\ of\ A|^2} \qquad 2$$

3) Skewness: Skewness refers to asymmetry in a statistical distribution when the curve seems distorted or skewed to the left or right. Skewness can be measured to determine how different the distribution is from a normal distribution. So, for N distribution of data, the standard deviation and mean of the distribution is σ and x¯, then skewness is defined as

$$Skewness = \frac{\sum_{i=0}^{N}(x-\bar{x})^3}{N-1 \times \sigma^3} \qquad 3$$

4) Kurtosis: Kurtosis is a statistical measure used to describe the peak of the distribution. So, for N distribution of data, the standard deviation and mean of the distribution is σ and $\bar{x}$, then kurtosis is define as

$$Kurtosis = \frac{\sum_{i}^{N}(x_i-\bar{x})^4}{(N-1)\times\sigma^4} \qquad 4$$

5) Dominant frequency: The highest magnitude sinusoidal component of the electrooculogram is described as dominant frequency, which is determined by applying FFT (Fast Fourier Transform) method which was mentioned in Mohsin et al [7] and selecting the one with the highest magnitude.

C. Import instance and dataset

In this study, a total of 450 instances with 14 attributes for each eye movement were imported into the machine learning algorithms to classify the EOG signal which was mentioned in the preceding sub-section.

D. SMOTE Algorithm

Machine learning algorithm faces problem when one class dominates over other class. That means there is imbalance of data. And to solve this imbalance problem in our study, we use SMOTE technique to balance the dataset. Synthetic Minority Oversampling Technique, also known as SMOTE is processes where new synthetic samples are create to minimize the imbalance of samples in a dataset by replicating the minority classes [8]. So, before SMOTE analysis, our dataset contained 450 samples but after balancing the dataset by SMOTE, the new large extend dataset contains 936 samples.

E. Dataset Splitting

Two sets of data were created: a training set and a test set, with the training set including 80% of the dataset's samples and the test set containing the remaining 20% [9]. The training set was then split again, with 20% of training samples being assigned to the validation set and the rest being used for training. To predict, the machine learning algorithms establishes a relation among the independent and dependent variables and after that the test sets and validation sets are used to find out whatever the algorithm is working accurately.

F. Feature Scaling

Objective functions in some machine learning algorithms will not work effectively without normalization since the range of values in raw data fluctuates greatly. A method for normalizing the range of independent variables or data features is feature scaling. It's also known as data normalization in data processing, and it's usually done as part of the data prepro- cessing step[10].

In this study, Standard Scalar python library used to nor- malize the extent of self-governing elements or features of data. During the data preprocessing step this procedure is normally executed.

G. *Application of the Machine Learning Algorithms*

Artificial Neural Network (ANN) has been used in this study which described in the following:

1) *Artificial Neural Network (ANN)*

Artificial Neural Network (ANN): There are many machine learning algorithms are available, one of them is Artificial Neural Networks (ANNs). The ANN algorithm is based on the brain's biological neurons, which perform similar functions. Brain has the ability to think the reasons behind any action and also has the capability to learn from the past experiences. There are approximately 100 billion neurons in the brain which are linked and the multiple connections between them. So, like a brain, ANN model tries to imitate the brain by neurons which are arranged in various layers, input layers, hidden layers and output layers. With the help of its layers, ANN algorithm can process complex and non-linear information and also has the ability to create reasoning method and functioning techniques [11].

Artificial Neural Networks (ANNs) is consists of three important layers and these layers nodes are connected to each other like neurons in the brain. These layers are input layer, hidden layer(s) and output layer. The data is accessed from the network by the input layer. After that the information is received from input and processed by the hidden layer. Then, the processed data is to be sent at the output layer where the information again processed and after that, it gives the output.

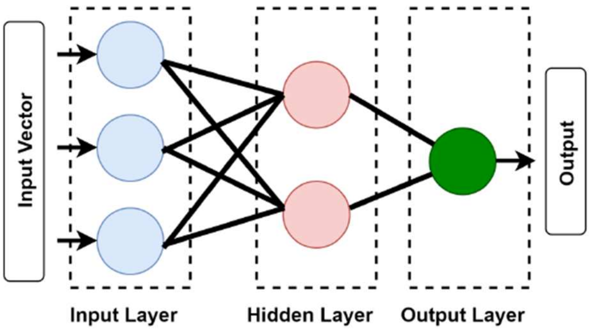

Fig. 4. ANN architecture.

There are several classes of ANN and Backpropagation of feed-forward ANN is one of them. It is a supervised learning algorithm and is used to train multi-layer ANNs. As back propagation feed-forward, ANN is a supervised learning algorithm, it is provided with instances of inputs and output. Then it calculated the error and began to adjust the weights to minimize the error until the desired output is computed [12]. In Fig. 4, a backpropagation of feed-forward ANNs is shown where it is clear that the input signals are sent forward while the backpropagation algorithm calculated the errors which then propagated backward.

In Fig.5, the architecture of ANN which has been used in this paper is shown. Form the Fig.5, we can say that the structure included two hidden layers along with an input and output layer. The input layer consists of 14 input nodes where the first hidden layer has double nodes of the input layer. On the other hand, the second hidden layer contains 18 hidden nodes which are also double in the number of output nodes in the output layer. We used "relu" and "softmax" as activation functions, and we declared batch size and epoch as 5 and 500 respectively.

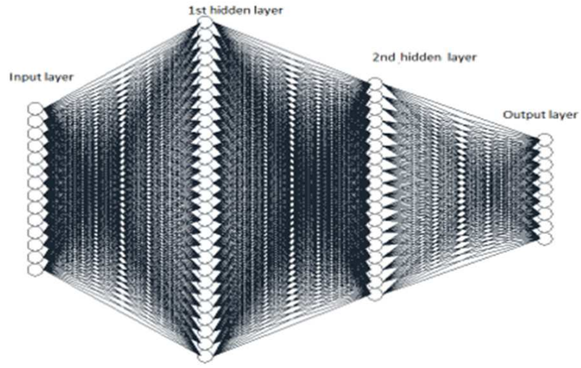

Fig. 5. ANN architecture in this study.

H. *Classification parameters:*

There are some parameters that need to calculate for analyzing the machine learning algorithm and they are Accuracy, Precision, Recall, and F1 score. These parameters can be calculated using the confusion matrix [13] to analyze the algorithm.

I. *Results and Discussions*

In this section, we will discuss the analysis and also discuss the result which we have gained from implementing ANNs machine learning algorithm in our work.

By observing Fig. 6(a), it is clear that the number of samples is not equal and the existence of a dominant class will create a problem for our algorithm. To solve this problem, we used SMOTE algorithm on our dataset to create synthetic samples from minority samples for reducing the imbalance of samples, as shown in Fig. 6(b).

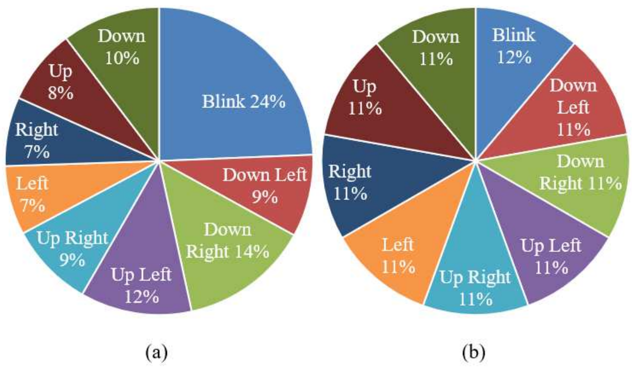

Fig. 6. (a) Sample percentages before SMOTE analysis, (b) Sample percent- ages after SMOTE analysis.

Fig. 7 illustrates the correlation features matrix. In statistics, correlation shows the relation between two variables or bi- variate data, whether it's causal or not. The ranges of value of correlation are between +1 and -1, here +1 denotes a perfect positive linear correlation between two pairs of attributes and on the other hand, -1 represents a perfect negative linear correlation between two variables. And 0 is for no linear correlation.

The correlation matrix contains the correlation values of 7 attributes from two channels, right and left eye. We can interpret that the dominant frequency is highly positively correlated between two channels which is 0.93. The correlation between standard deviation and mean for channel-1 and channel-2 is also strongly positive which are 1 and 0.99 respectively. Also a strongly negative correlation of -0.98 and

-0.93 can be found between standard deviation and minimum value of channel-1 and channel-2.

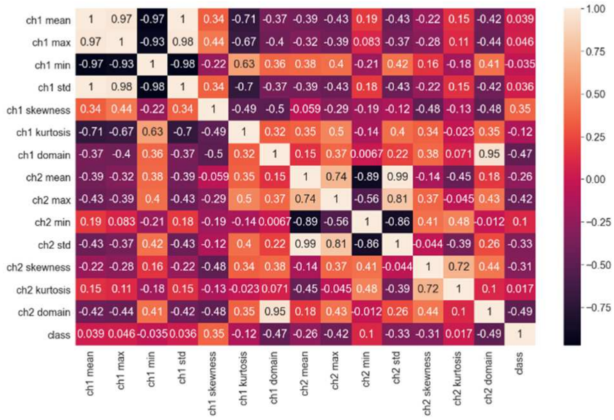

Fig. 7. Correlation matrix of the EOG features. Ch1 and Ch2 refers to channel 1 and 2 respectively.

Fig. 8 illustrates the training accuracy vs. validation accuracy graph. Before testing our 20% of samples by ANN machine leaning algorithm, we trained our model with training sample set and used validation sample set to test the fitness of our model. Here, two sets of data were developed; training set and test set where training set contains 80% of samples of the dataset and the rest remains as test set. The training set was split again in a way that 20% of training samples were assigned as the validation set and the remaining was employed for the training. From Fig. 8, it is clear that after every epoch, the performance of the model improved and after a certain epoch, the accuracy of the model was stabilized close to 100%.

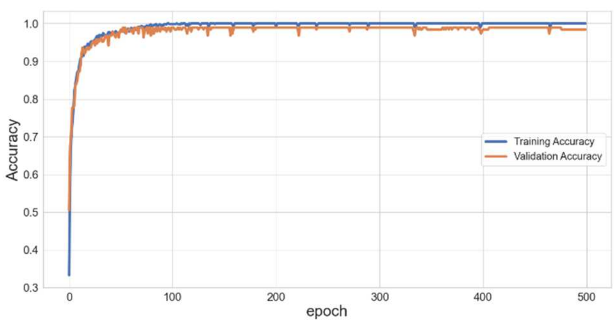

Fig. 8. Training and validation accuracy variation with epoch.

After the training accuracy vs. validation accuracy, we moved towards to predict the classes of Electrooculography signals including blink up, down, left, right, down left, down right, up left and up right using our ANN machine learning algorithm. We tested the test set of samples in our trained model for predicting the classes and also calculated the classification parameters: accuracy, recall, precision and F1 score. Table I. provides the result of classification parameters of ANN algorithm. The accuracy of Artificial Neural Network algorithm was 99%. The weighted avg. of F1 score was found 99% in ANN algorithm. The weighted avg. of recall and precision were also 99% for each.

TABLE I. MODEL PERFORMANCE

Algorithm	Accuracy	Recall	Precision	F1 Score
ANN	99%	99%	99%	99%

In Table 2, a comparison is shown between our and other contemporary studies. Some papers have a good accuracy of their applied machine leaning algorithm. KNN was applied for 6 classes and a 96.9% of accuracy has been observed. 98% of accuracy for decision tree algorithm was obtained for only 2 classes.

TABLE II. COMPARISON TABLE

Ref	Alg	Ac.	Re.	Pr.	F1	cls
[3]	DTCWT-SVM	96.11%	-	-		4
[4]	SVM	95.83%	-	-		2
[5]	SVM	76.1%	-	70.5%	76.1%	3
[6]	KNN	96.9%	-	-		6
[6]	SVM	96.8%	-	-		6
[6]	Decition Tree	95.4%	-	-		6
This Study	**ANN**	**99%**	**99%**	**99%**	**99%**	**9**

Ref: Refference, Alg: Algorithms, Ac: Acccuracy, Re: Recall, Pr: Precision, F1: F1 Score, cls: Class

In this study, the ANN machine learning algorithm executed for 9 class classifier to predict the electrooculogram (EOG) signals of eye movements. In our study, the ANN algorithm provides a topnotch performance to predict the 9 class EOG signal with an accuracy of 99% which very good compare to the other papers. We classified 9 class of EOG signals and they are: blink, up, down, left, right, down left, down right, up left and up right, where most of the studies based on much less classifier than ours. Though, in our study, our ANN algorithm has the best accuracy but we are lagged behind by the number of accuracy.

IV. CONCLUSION

The primary goal of this research was to identify the 9 class electrooculogram (EOG) signals with strong accuracy. For this purpose, we separated of work in various segment and carefully completed every single segment from data collection to parameters classification via applying ANN machine learning algorithm. We have run through our samples into the SMOTE algorithm to balance our dataset and also calculated recall, precision and F1 score. We also observed the correlation of features. We implemented the ANN machine learning algorithm to classify the 9 classes of EOG signal. And our result show that ANN algorithm successfully performs to classify the classes of EOG signal with an accuracy of 99%. The ANN algorithm also acquired an utmost of 99% of value for each classification parameters. So, as a conclude statement, we can say that based on our approach and analysis that ANN machine learning algorithm can be implemented successfully to classify multi class EOG signal and can predict its signal properties for smart wheelchair.

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