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EOG Signal Classification Using Neural Network for Human Computer Interaction

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ABSTRACT

Human Computer Interaction (HCI) using Electrooculography is one of the growing research fields in recent years. HCI provides a communication channel between human and external device. EOG is used to detect activities of human eye movements. In this paper eleven different eye movement tasks from ten subjects were studied. The proposed Parseval Theorem was implemented for feature extraction. A Feed Forward Neural Network (FFNN) and Time Delay Neural Network (TDNN) were implemented for classification. The average classification accuracies were observed to vary from 80.72% to 91.48% and 85.11% to 94.18 % for the eleven different eye movement tasks for each of the subjects to create nine states Human Computer Interface. The results confirm that dynamic neural networks were more suitable for designing nine states HCI system for disabled person to control external devices.

Keywords: Electrooculography, Human Computer Interaction, Parseval Theorem, Feed Forward Network, Time Delay Network, Fast Fourier Transform.

1. INTRODUCTION

Electrooculography (EOG) is a new technology of recording both horizontal and vertical eye movements by measuring small electrical potentials difference between cornea and retina. The resultant signal is called electrooculogram. Human-computer interaction (HCI) is the study of the interaction between people and computers [1]. A HCI detects the specific patterns activity and translates these patterns into meaningful commands [2]. The HCI systems use bio potentials EOG electrical signals generated from human body to control external devices. This technology aims to increase and maintain their communication, control options for severely elderly disabled [3]. People with severe disabilities like Brainstem lesion, Stubor, Appoploxy only retain their control capacity over the oculomotor system. An efficient alternative way to communicate without speech and hand movements is important to increase the quality of life for elderly disabled. Therefore, the focus on the development of new HCI and communication systems based on the detection of eye position has increased in the last few years [4]. Human machine Interfaces have received more and more attention of researchers in recent years [4]. Several HCI using EOG had been developed to control variety of applications such as tongue controller system[5], eye writing recognition[6], tooth click controller[7], hospital alarm system[8], virtual Keyboard[9], myo-electric controller[10], vision based system[11], electric wheel chair[12], Mobile robot control[13], cursor mouse control[14], eye activity recognition[18], eye exercise recognition[19], wireless mouse[20], speech recognition system[21], speaker recognition system[22]. Eye movements can be classified into eight basic movements namely up, down, right, left, up-right, up-left, down-right and down-left. Most of the HCI's are using the first four directions to develop device for elderly disabled [27] - [32]. In this study we additionally included four more eye movements' tasks in order to verify the nine states HCI. The proposed additional four movements are Rapid Movement, Lateral Movement, Open, and Stare.

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This paper is divided into three main parts. The Section I introduces needs of EOG based HCI while section II presents in details about EOG and Extraoocular muscles. Section III specify the Experimental protocol, acquisition, pre-processing, feature extraction and signal classification techniques used in this research. Experimental results and discussion is specified in Section VI.

2. ELECTROCULOGRAPHY

EOG is the technique of sensing eye movements by recording the cornea- retinal potential that exists between the front and the back of the human eye. To measure eye movements, pair of electrodes is typically placed above and below the eye and to the left and right of the eyes. The eye acts as a dipole in which the anterior pole is positive and posterior pole is negative. Human eyeball can be considered as a spherical battery with the center of the cornea as positive and the retina as negative. The micro currents flow radially from the positive pole to the negative pole of the battery through the conductive tissue in the path. These currents generate the standing potentials around the eye, and the micro potentials (EOG) can be detected from the skin electrodes pasted on the surface of the canthus. The potential of the EOG varies from 50 to 3500µV. 20µV changes are seen for changes in each degree of eye movement. [33].

Eye position and motion are controlled by six muscles in each eye. The six muscles are Medial Rectus (MR), Lateral Rectus (LR), Superior Rectus (SR), Inferior Rectus (IR), Superior Oblique (SO) and Inferior Oblique (IO). MR muscles perform the movement of moving the eye inward, toward the nose. LR moves the eye outward, away from the nose. SR muscles primarily moves the eye upward, secondarily rotates the top of the eye toward the nose, tertiarily moves the eye inward. IR muscles primarily execute the eye downward, secondarily rotate the top of the eye away from the nose, tertiarily moves the eye inward. SO primarily make rotates the top of the eye toward the nose, secondarily moves the eye downward, tertiarily moves the eye outward and IO muscles mostly rotate the top of the eye away from the nose. Secondarily moves the eye upward, tertiarily moves the eye outward. Each movement that elevates or depresses needs the participation of a minimum of 2 muscles of the axis of the orbit and also the muscles visual axis. The primary function of the four rectus muscles, namely SR, MR and IR, LR are used to control the eye movements from left to right and up and down. Top and bottom rotations are controlled by the SO and IO. These six tiny muscles that surround the eye and control its movements are known as the extra ocular muscles [34] [35]. In this study, however Right (R), Left (L), Upright (UR), Downright (DR), Upleft (UL), Downleft (DL), Rapid Movement (RM), Lateral Movement (LM) are considered as events and Open (O), Close (C), Stare (S) is considered as a non event because most subjects have difficult in voluntarily controlling blinks for a quick duration of 80ms.

3. MATERIALS AND METHODS

3.1. Experimental protocol

Sixteen eye movements were studied in initial studies and it was found that eleven eye movements could be voluntarily controlled; the remaining five eye movements were difficult to be controlled by all subjects. From the chosen eleven movements eight movements are considered as events and three are taken as non events to design nine states HCI. The protocols for eleven eye movements for designing the nine states HCI are given below:

Task 1→Right: Subject is requested to move both the eyes synchronously and symmetrically in the right direction to achieve this moment. LR and MR muscles are involved in this task.

Task 2→Left: Subject is asked to move both the eyes synchronously and symmetrically in the left direction. MR and LR muscles are responsible for this movement.

Task 3→Up Right: subject is told to move both the eyes synchronously and symmetrically in the upper right direction to complete the task. SR and IO muscles are in charge of this movement.

Task 4→Down Right: Subject is instructed to move both the eyes synchronously and symmetrically in the down right direction. IR and SO muscles are accountable for this task.

Task 5→Up Left: Subject is requested to move both the eyes synchronously and symmetrically in the upside left direction. IO and SR muscles are occupied with this task.

Task 6→Down Left: Subject is initiating to move both the eyes synchronously and symmetrically in the down left direction. SO and IR muscles are engaged in this movement.

Task 7→Rapid Movement: Rapidly moving both the eyes from left to right and right to left are called rapid movement. The subject is requested to move both the eyes synchronously and symmetrically in the same direction quickly and repeatedly. MR and LR muscles are responsible for this task.

Task 8→Lateral Movement: Lateral movement is achieved by moving both eyes slowly from left to right or vice versa. The subject is told to move both the eyes synchronously and symmetrically in the same direction slowly and repeatedly. MR and LR muscles are involved in this task.

Task 9→Open: The external, visible portions of the organ called eyelids are open slowly together to focus is called open. Subject is instructed to open both the eyes slowly together. SR and IR muscles are engaged in this movement.

Task 10→Close: The eyelids are closed slowly together to cut off the focus is called close. Subject is requested to close both the eyes slowly together to achieve this task.SR and IR muscles are involved in this movement.

Task 11→Stare: Subject is instructed to maintain the visual gaze on a single location to complete the task. SR and IR muscles are implicated in this movement.

3.2. Signal Acquisition

EOG signals of the eight eye movements (events) and three eye movements (non-events) were acquired using a two channel ADInstrument Bio-signal amplifier. Five gold plated, cup shaped electrodes were placed above and below the right eye and right side, left side of the eye and ground electrode was placed on the forehead is shown in fig.1. Ten subjects (7 Males, 3 Females) are participated in the experiment. All subjects who participated in the experiments were university students and staff aged between 21 and 44 years and voluntarily registered in the study. It was ensured that all subjects were healthy and free from illness during the acquisition. Subjects were seated in a comfortable chair in front of marked wall and

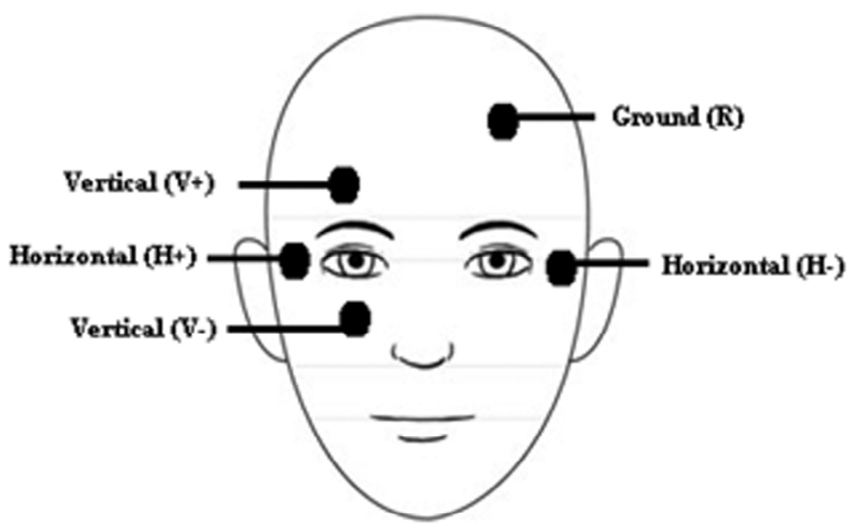

Figure 1: Electrode Placement

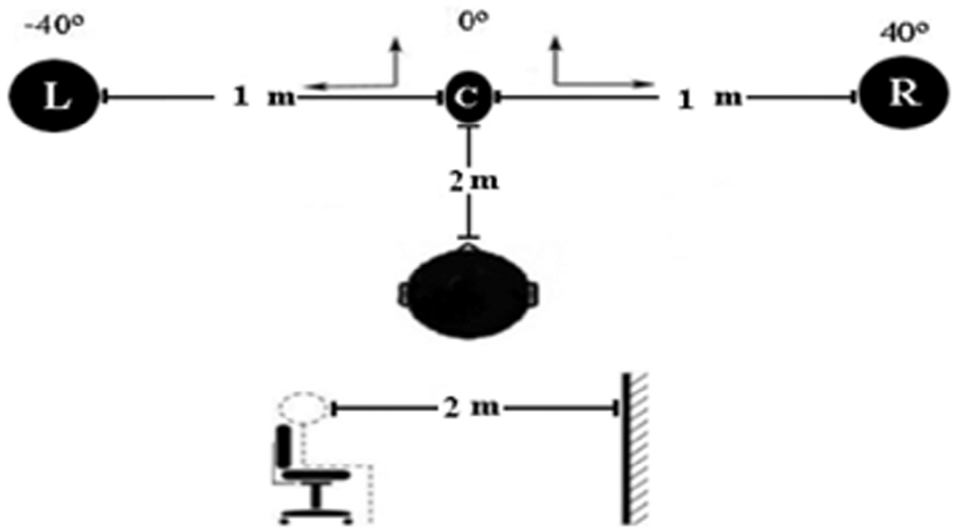

Figure 2: Subject Position During Signal Acquisition

requested not to make any overt movements during data acquisition is shown in fig.2. Subjects were given the eleven eye movement tasks to be executed by moving their eyes as per the protocol given for each task. Normally EOG signals are sampled at 128Hz. Since the proposed method has 2.8% reduced data processing time with slight accuracy sacrifice, this will greatly simplify the design and implementation of a microprocessor-based HCI, the frequency is assumed to be 100Hz. During signal acquisition a notch filter was applied to remove the 50Hz power line artifacts. EOG signals evoked by all the eleven tasks stated above were recorded from ten subjects. Each recording trial lasts for two seconds. Ten trials were recorded for each task. A subject was given a break of five minutes between trials and data were collected in two sessions, each session has five trials per task. All trials for a single subject were conducted on the same day. For each subject, a data set consisting of 110 sets (11 tasks x 10 trials per task) of EOG signals was formulated. The data sets of all the subjects were combined and a master data set consisting of 1100 trials of EOG signals was formulated.

3.3. Feature extraction

A spectral distribution analysis done on the signals showed that the eight movements chosen as events were found to have frequency components in the range of 5-8 Hz while the non event eye movements frequency components in the range of 6-9 Hz and also further more information is discussed in our previous study[35]. The raw EOG signals have to be further processed to isolate the event and the non event frequency range. Since artifacts due to EEG, EMG of the facial muscles, position of the electrodes, head and facial moments, lighting conditions and eye blinks signal can be removed by a bandpass filter. Eight frequency bands are extracted using a Chebyshev bandpass filters by split the signal in the range of two Hz to filter the noisy data. The eight frequency ranges are (0.1-2) Hz, (2-4) Hz, (4-6) Hz, (6-8) Hz, (8-10) Hz, (10-12) Hz, (12-14) Hz, (14-16) Hz. Feature extraction algorithm based on the Parseval theorems is proposed to extract the features from each band. Feature extraction algorithm uses the following procedure

A) Bandpass filters are applied to extract the eight frequency band signals.

B) Apply FFT for frequency band and extract absolute value from band signals.

C) Square the values.

D) Sum the values

E) Extract average from step D.

F) Repeat A to E for each trial.

The energy features from each segmented signal is extracted using the Parseval theorem. Sixteen features were extracted for each trial per task per subject. Using the Parseval theorem concept the total energy of the EOG signal is extracted and is used as a feature to train neural network classifiers.

3.4. Signal Classification

To classify the EOG signal extracted from the eye movement's two neural network models are designed. This study uses the Feed Forward Neural network and Time Delay Neural Network to classify the eleven different EOG data signals. Fig.3 shows the architecture of the Feed Forward Neural Network model with eight hidden neuron used in this study. The FFNN is trained using Levenberg back propagation algorithm to classify the eleven eye movement's task represented by the EOG features. A Feed Forward Neural Network with sixteen input neuron and four output neuron is considered to classify the EOG features. The numbers of hidden neurons are chosen experimentally. The hidden neurons are chosen by trial and error method. Three hidden neuron configuration networks are modeled for 6, 7, 8 hidden neurons. Thirty network models are developed and experimentally verified for each network.

A TDNN with 6, 7, 8 hidden neuron architecture is chosen to classify the eleven different eye movements tasks. Fig.4.shows the architecture of the Time Delay Neural Network model with eight hidden neuron used in this study. The TDNN is trained using Levenberg back propagation algorithm to classify the eleven eye movement's task represented by the EOG features. Time Delay Network with sixteen input neuron and four output neuron is considered to classify the eleven different EOG features. The numbers of hidden neurons are chosen experimentally. The hidden neurons are chosen by trial and error method. Three hidden neuron configuration networks are modeled for 6, 7, 8 hidden neurons. Thirty network models are developed and experimentally verified for each network.

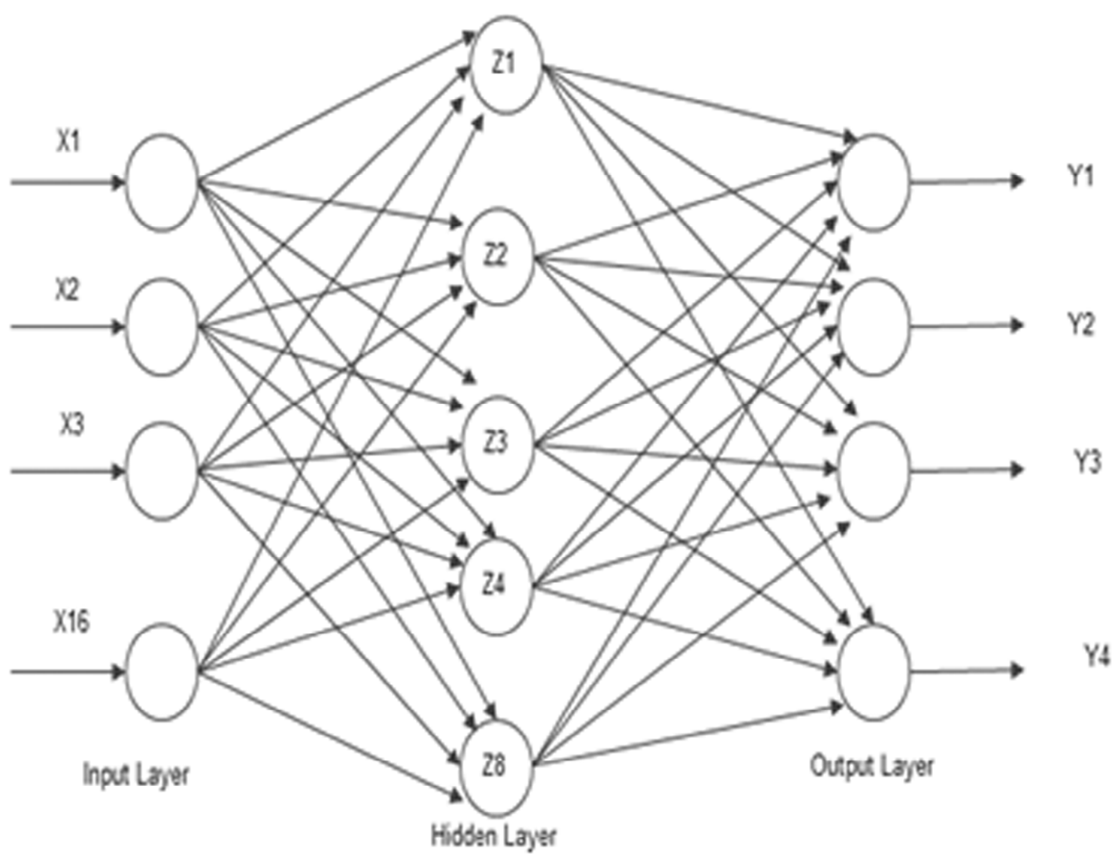

Figure 3: Feed Forward Neural Network Model

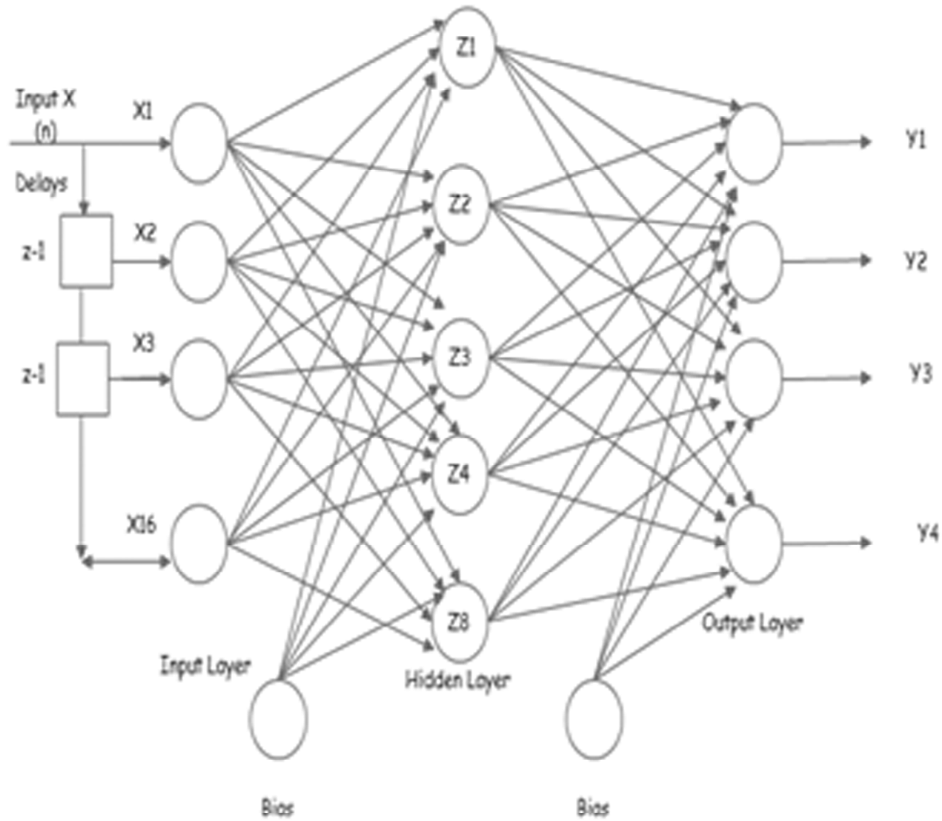

Figure 4: Feed Forward Time Delay Network Model

4. RESULT AND DISCUSSION

1100 data samples are used in the experimentation. Sixty network models are analyzed and the results are shown in Table1 for the FFNN and TDNN respectively. 110 data samples are used in the experiment analysis per subject. The FFNN is tested and trained with 6, 7, 8 hidden neuron respectively. The training and testing samples are normalized between 0 to 1 using binary normalization algorithm. Selections of the training data are chosen randomly. The learning rate is chosen to be 0.0001 experimentally. Out of the 110 samples 75% of the data are used in the training of the network and 100% of the data are used in the testing the network. The Neural Network is trained with the levenberg back propagation algorithm. Training is conducted until the average error falls below 0.001 or reaches maximum iteration limit of 1000. The Neural Network is tested with 100% data samples for each task. The Neural Network is tested for testing tolerance of 0.1 to evaluate the performance of network. . From the result it is observed that the mean performance of the FFNN varies from 80.72% to 91.48%. Standard deviation of 1.84 was achievable for subject 6 with eight hidden neurons is shown in Table1. The average learning time varies from 7.99 sec to 9.38 sec. While the testing time range is 0.71 sec to 1.01 sec. The best results were obtained for subject10 with eight hidden neurons. The network model with eight hidden neurons showed better performance for subject 2, subject3, subject 4, subject5, subject7, subject8, subject9 and subject10. Best performance of 91.48 % was achieved for subject10 using Parseval features for FFNN with eight hidden neurons. The training and testing time is in the range of five sec and one sec respectively for all subjects.

110 data samples are used in the experiment analysis per subject. The TDNN is tested and trained with 6, 7, 8 hidden neuron respectively. The training and testing samples are normalized between 0 to 1 using binary normalization algorithm. Selections of the training data are chosen randomly. The learning rate is chosen to be 0.0001 experimentally. Out of the 110 samples 75% of the data are used in the training of the network and 100% of the data are used in the testing the network. The neural network is trained with the

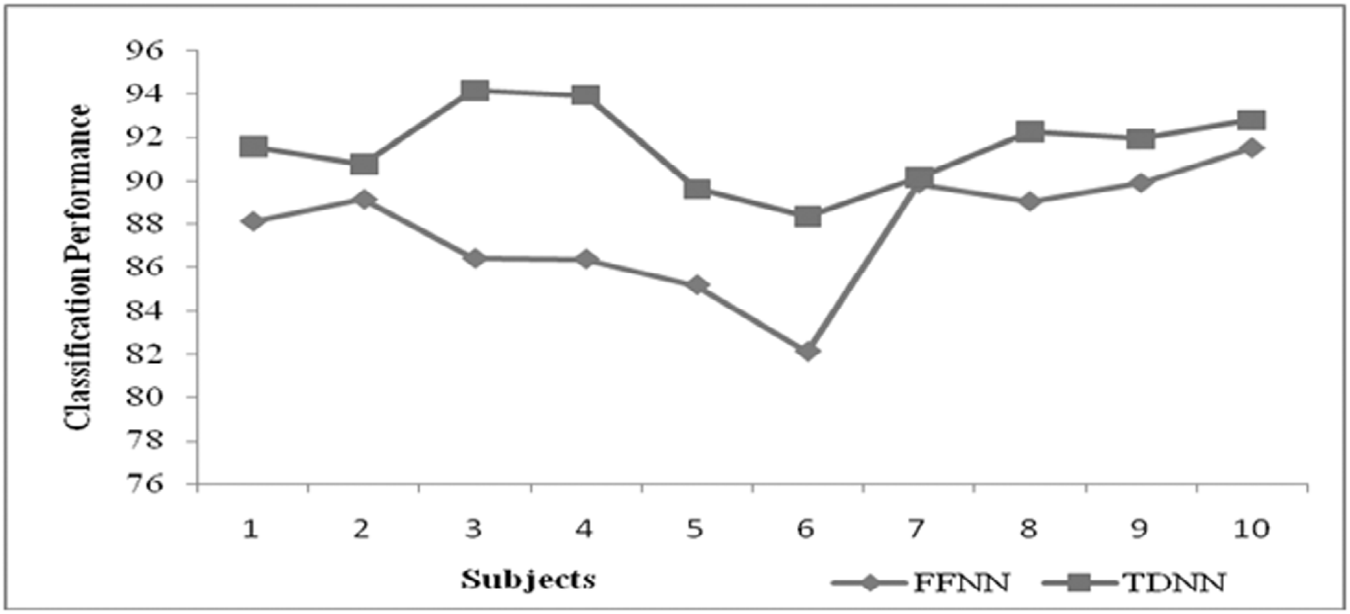

Figure 5: Comparision chart for FFNN and TDNN using Parseval features with eight hidden neuron

levenberg back propagation training algorithm. Training is conducted until the average error falls below 0.001 or reaches maximum iteration limit of 1000. The Neural network is tested with 100% data samples for each task. The Neural Network is tested for testing tolerance of 0.1 to evaluate the performance of network. From the result it is observed that the mean performance of the TDNN varies from 85.11% to 94.18 %. Standard deviation of 1.59 was achievable for subject 5 is shown in Table.1. The average learning time varies from 1.33 sec to 1.45 sec. While the testing time range is 0.69 sec to 0.98 sec. The best results were obtained for subject3 with eight hidden neurons. The network model with eight hidden neurons showed better performance for subject1, subject2, subject3, subject4, subject5, subject6, subject7, subject8, subject9 and subject10. Best performance of 94.18% was achieved for subject3 is illustrated in the Table1. The training and testing time is in the range of five sec and one sec respectively for all subjects. The performance of the TDNN is comparatively better with mean classification rates varying from 85.11% to 94.18 %. The results show that TDNN network models are more suitable for classifying the EOG signals for eleven different EOG tasks. Fig.5. shows the comparison chart of FFNN and TDNN models using Parseval features with eight hidden neurons far all ten subjects.

5. CONCIUSION

EOG signals recorded from ten individuals were used in this experiment. A new feature extraction algorithm has been implemented for extracting features from different eye movements. In order to test the proposed features, two simple Neural Network models are developed for classifying the eleven different eye movements. The results shows that eye movement classification vary from subject to subject. A maximum classification of 94.18% is achieved for subject3 using TDNN. Classification performances were observed to be much better with 8 hidden neurons. The results obtained from this research validate the feasibility of identifying the eleven eye movements for designing nine states HCI using EOG signal. However the feasibility of the nine states HCI has to be verified in online studies which are the future focus of the work.

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Table 1
Classification Performance of FFFN and TDNN Using Parseval Feature

S. no	*Sub*	*Hidden Neuron*	*Mean Training Time*	*Mean Testing Time*	*Classification Performance for FFNN*				*Mean Training Time*	*Mean Testing Time*	*Classification Performance for TDNN*			
					Max	*Min*	*Mean*	*SD*			*Max*	*Min*	*Mean*	*SD*
1	S1	6	8.96	0.81	91.11	77.78	83.74	3.92	1.34	0.77	97.78	86.67	90.53	3.03
		7	9.38	1.01	93.33	84.44	88.84	4.02	1.34	0.77	96.67	81.11	89.34	3.37
		8	9.83	0.77	93.33	80.00	88.09	2.44	1.33	0.77	98.89	85.56	91.56	3.64
2	S2	6	8.66	0.87	90.00	78.89	84.83	3.23	1.35	0.72	95.56	84.44	89.95	3.39
		7	9.14	0.79	92.22	82.22	88.02	3.25	1.37	0.69	98.89	84.44	90.04	3.55
		8	9.81	0.76	95.56	84.44	89.11	2.92	1.40	0.73	97.78	84.44	90.77	2.97
3	S3	6	8.76	0.71	91.11	80.00	84.45	3.28	1.43	0.72	98.89	88.00	92.50	2.49
		7	9.02	0.68	92.22	81.11	85.53	3.41	1.37	0.70	98.89	87.78	92.38	3.15
		8	9.66	0.70	95.56	82.22	86.40	3.08	1.45	0.71	97.78	90.00	94.18	3.09
4	S4	6	8.78	0.72	85.56	76.67	80.72	2.44	1.36	0.76	97.78	84.44	91.85	2.83
		7	9.08	0.77	88.89	81.11	85.71	2.18	1.38	0.82	97.78	89.00	93.48	2.83
		8	9.74	0.72	90.00	81.11	86.37	2.52	1.43	0.91	98.89	90.00	93.95	3.18
5	S5	6	8.82	0.76	87.78	77.78	81.82	2.34	1.38	0.98	92.22	81.11	85.11	1.59
		7	9.05	0.72	87.78	80.00	84.48	3.81	1.36	0.95	90.00	81.11	85.96	2.28
		8	9.68	0.74	94.44	80.00	85.16	2.36	1.38	0.91	92.22	86.67	89.61	2.65
6	S6	6	8.70	0.79	84.44	77.78	81.05	1.84	1.35	0.80	90.00	80.00	85.64	2.11
		7	9.09	0.75	88.89	80.00	84.38	2.46	1.36	0.84	91.11	81.11	85.70	2.53
		8	9.68	0.75	85.56	79.00	82.11	2.29	1.38	0.88	92.22	83.33	88.33	2.62
7	S7	6	8.74	0.75	92.22	81.11	87.17	2.87	1.37	0.86	93.33	81.11	87.43	2.93
		7	9.23	0.74	93.33	84.00	89.29	2.89	1.38	0.85	93.33	83.00	88.27	2.69
		8	9.78	0.79	95.56	83.33	89.84	3.02	1.39	0.90	94.44	84.44	90.15	2.91
8	S8	6	8.29	0.71	92.22	80.00	85.43	2.89	1.39	0.89	97.78	88.00	91.65	2.90
		7	7.99	0.73	93.33	83.33	88.83	2.07	1.40	0.88	97.78	87.00	92.12	2.93
		8	8.62	0.72	93.33	84.44	89.01	2.29	1.43	0.86	97.78	87.78	92.26	2.53
9	S9	6	8.75	0.75	92.72	80.00	86.21	2.84	1.41	0.87	97.87	88.00	91.82	2.69
		7	9.19	0.73	92.22	85.56	88.85	2.38	1.39	0.85	95.56	85.56	89.97	2.68
		8	9.74	0.74	93.33	85.11	89.87	1.95	1.43	0.86	97.78	87.78	91.91	2.67
10	S10	6	8.72	0.72	92.22	81.11	85.46	2.72	1.36	0.87	93.33	83.33	88.32	2.44
		7	9.06	0.72	95.56	86.67	90.67	2.52	1.36	0.83	94.44	81.11	87.91	2.87
		8	9.48	0.73	95.56	86.67	91.48	2.31	1.40	0.84	97.78	89.98	92.78	2.85

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