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A Brain Computer Interface based Communication System using SSVEP and EOG

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Abstract

This study aims to design a high performance communication system using steady state visual evoked potential (SSVEP) and electro-oculogram (EOG) signal. The proposed keyboard system consists of twenty three randomly chosen characters and they were indexed into different flickering visual stimuli designed using three SSVEP stimulus frequencies. The same frequency valued visual stimuli were used many times (more than once) in the keyboard layout. In this approach an oddball paradigm is introduced and it randomly highlights three/two unique frequency valued visual stimuli at a time. The system identifies a desired target by user eye blink in accordance to the oddball paradigm and recognized SSVEP frequency value. The signal to noise ratio (SNR) of the real time SSVEP electroencephalogram signal gets increased by the introduction of oddball paradigm in the SSVEP based keyboard system. The paradigm will increase the subject's attention and concentration on the flickering target stimulus. The real time SSVEP data were classified using extended multivariate synchronization index (EMSI) method. The thresholding method is used for single blink detection. The offline and online experiments were performed by all the subjects for evaluating the proposed communication system. The average classification accuracy and information transfer rate of the system are 96.73 % and 76.02 bits/min respectively.

Keywords: Brain Computer Interface (BCI); Steady State Visual Evoked Potential (SSVEP); Keyboard system; Electrooculogram (EOG).

1. Introduction

In the past three decades electroencephalogram (EEG) based BCI devices/systems are enabling the communication between impaired/disabled people and their surrounding world [1]. The EEG, EOG and hybrid EEG based spelling/keyboard system was developed as a communication system for disabled people to deliver their

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intentions/thoughts. They can use their brain signals to type/spell the words for interaction. The commonly used EEG components in BCI systems are SSVEP, P300, event related synchronization and desynchronization signals [1,2]. Most of the real time BCI keyboard system uses SSVEP component as a control signal, because it is easy to elicit with less training or even with no training. The SSVEP is a periodic EEG component elicited in response to the flickering visual stimulus designed at a frequency above 5 Hz [3]. The SSVEP component is primarily occurring in the occipital region of the human brain and the SNR of this signal is high as compared to the other EEG components. Due to its advantages like less training time, high information transfer rate and high SNR, the SSVEP component was generally used in many BCI based keyboard applications [3-6]. It also has some limitations on the visual stimulus design and the number of targets. The visual stimulus flickers at a frequency (F1), which elicits strong SSVEP response at fundamental and harmonics of F1, so the harmonics of F1 frequencies could not be used for other SSVEP visual stimulus frequencies [7,8]. The stimulus frequency should be an integer division of monitor refresh rate, therefore the number of targets is limited in SSVEP systems. Recent studies show that, the sampled sinusoidal simulation method, coding techniques and dual frequency methods were introduced for designing more SSVEP targets [9-11]. Even though the SSVEP based system has achieved an increased number of targets using the above techniques, the probability of target classification rate is low. In this study, the keyboard system with more targets were designed using three stimulus frequencies. The probability of target detection rate is high as compared to the other existing systems. In this proposed SSVEP-EOG system the same frequency valued visual stimuli were used many times in the keyboard layout. Therefore the number of targets were increased. The oddball paradigm is randomly highlights all the targets stimulus in the keyboard layout and the subjects/users were instructed to blink once the corresponding target was highlighted by the oddball paradigm. The desired target was identified by using both eye blink and SSVEP signal. The proposed study presents a simple and convenient SSVEP-EOG based keyboard system with more targets, high classification accuracy and high information transfer rate.

The paper is organized as follows. Subjects and data acquisition, speller/keyboard design, experimental paradigm and procedures, eye movement detection and feature extraction are described in section 2. The results of offline and online analysis are presented and discussed in section 3 and 4 respectively. The summary of the paper is concluded in section 5.

2. Methods

2.1. Subjects and data acquisition

Ten healthy subjects were recruited for the proposed SSVEP-EOG keyboard system validation. The EEG and EOG data were acquired using indigenously developed data acquisition system, BioDaq v01. The data acquisition system was developed at Biomedical Instrumentation and Signal Processing (BISP) Lab, Indian Institute of Technology Madras. The data acquisition system consists of ADS1299, 24 bit, 8 channel analog front end IC manufactured by Texas Instruments [12]. The EEG data were acquired from the electrode locations O1, O2, PO3, PO4, POz and Oz as per the international 10-20 electrode system. Fig. 1 shows the electrode locations for EOG data acquisition. Two surface Ag/AgCl electrodes (A and B) were placed on the vertical axes of the right eye to record the single blink eye movement and electrode C is connected to ground. The EEG and EOG data were acquired at the rate of 250 Hz and further the EOG data were down sampled to 32 Hz for removing minor fluctuations. The acquired EEG and EOG data were applied to bandpass filter (0.1 to 40 Hz) and notch filter (50Hz) for removing noise and power line interference.

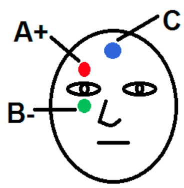


Fig. 1. EOG Electrode placement

2.2. SSVEP-EOG keyboard system design

The square checkerboard (3X3) pattern was adopted for SSVEP visual stimulus design. The input visual stimuli were designed using Processing (Java based) software platform. Three frequencies 6, 7.5 and 10 Hz were used for SSVEP stimulus design and these are integer divisions of monitor refresh rate 60 Hz. The same frequency valued visual stimuli were used in many places on the keyboard layout. In this study, we have randomly chosen twenty three characters and they were indexed into different flickering visual stimuli shown in Fig. 2. The designed visual stimuli were projected on the extended monitor shown in Fig. 3. The chosen characters and their corresponding stimulus frequency values are shown below.

- 6 Hz - Q, T, A, F, K, Z, J, B
- 7.5 Hz - W, I, O, S, G, X, N
- 10 Hz - E, Y, P, H, L, C, V, M

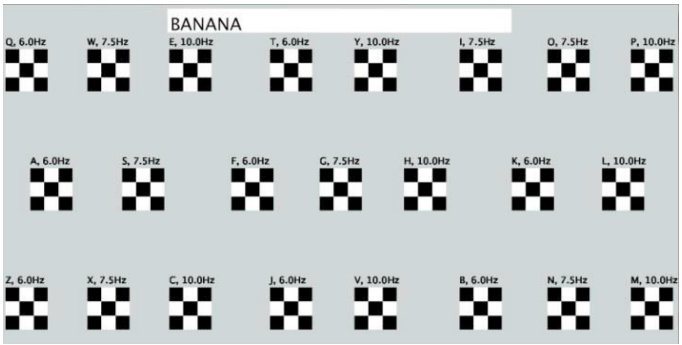


Fig. 2. Keyboard layout

Beginning of the experiment, the subjects were asked to sit in a comfortable arm rest chair facing towards the extended monitor and the distance between the monitor and subject was maintained as 50 cm. The proposed SSVEP-EOG system shown in Fig. 3 and it consists of an extended monitor, personal computer (processor), data acquisition unit (BioDaq v01) and electrodes for EEG and EOG acquisition.

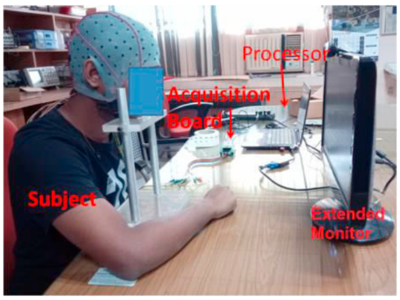


Fig. 3. Experimental setup

2.3. Experimental paradigm and procedure

The 23 chosen characters were almost equally indexed to 6, 7.5 and 10 Hz visual stimuli. The experiment is initiated by turning the background/edge of all stimuli into green color.The experimental paradigm starts by highlighting 2 or 3 unique frequency valued target in blue at the same time, shown in Fig. 4. The randomly chosen characters will be in blue color for 350 ms followed by an inter stimulus interval of 50 ms. In a single sequence all the target characters were highlighted once with blue color. The total time required to complete one sequence is (8-times X 400 ms) 3.2 second. The subjects were instructed to blink, once the desired target was highlighted with blue color. The desired target highlighted time (by oddball paradigm) was calculated from the eye blink signal. The recognized SSVEP frequency value and eye blink time were used for desired target identification. If the subject is not performing any eye movement in a single sequence, then the paradigm again starts highlighting the targets (next sequence).

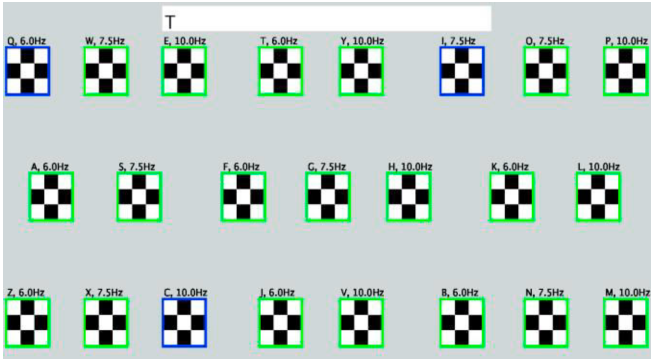


Fig. 4. Keyboard layout with oddball paradigm

The experimental procedure is divided into two phases, 1) training phase and 2) testing phase. Training phase consists of two experiments, estimating the features/threshold values for eye movement detection (offline EOG analysis and calibrations) and SSVEP response time detection. The testing phase was divided into cue guided, free spelling task and word spelling task. The extended multivariate synchronization method was used for SSVEP frequency recognition [13].

2.4. Eye movement detection and feature extraction

As explained in section 2.1 a set of three surface Ag/AgCl electrodes were used to collect the EOG data shown in Fig. 1. The electrodes A and B were connected in a bipolar configuration of the amplifier. The subjects were asked to blink forty times as per the instruction from the cue guided system. The respective eye movement data were stored and indexed by subject number. The average threshold value for an eye blink detection were calculated from the offline EOG data. The maximum and minimum amplitude, standard deviation, duration, peak and valley were calculated from the differentiated version of acquired EOG data. The Fig. 5 shows the original and a differentiated version of the single blink signal. After extracting the features of an eye blink event, the subjects were asked to perform blink event with various strong head movement, to check whether the eye movement detection algorithm was working properly. Almost 99 percent classification accuracy was obtained for single blink detection.

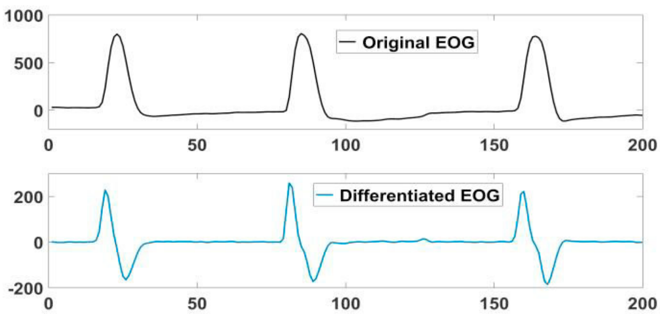


Fig. 5. First order differentiated version of acquired eog signal (x-axis represents the number of samples and y-axis represents amplitude in micro volts)

3. Experiments and Results

3.1. SSVEP response time detection

The SSVEP response to the input visual stimulus depends on the subjects and it will vary across the subjects. In order to find an optimal SSVEP stimulation window for online speller application, a five session of offline experiments were performed on all the subjects. The offline GUI consists of three stimuli flickering at 6, 7.5 and 10 Hz. The cue guided system starts to highlight the flickers one by one and the subjects were tasked to give attention on the highlighted stimulus. The single stimulus was highlighted for 5 seconds (SSVEP time window), followed by an inter stimulus interval of 1 second (rest window). In single session all three visual stimuli were highlighted once as SSVEP stimulus window followed by rest window. During rest window the highlight was made to disappear and the subjects were instructed to relax. Five sessions of offline EEG data were collected from all ten subjects for finding an optimal SSVEP time window.

The offline EEG data were classified at different time window lengths 2, 2.5 and 3 seconds from the original 5 second time window. The EEG data were fed into EMSI algorithm for SSVEP frequency recognition at different time window lengths. The SSVEP classification accuracy was calculated from the output of EMSI algorithm. Fig. 6 shows the SSVEP classification accuracy of all the subjects at different time window lengths. The averaged classification accuracy of 96.66% was achieved at 3 second time window across all the subjects. Therefore, the oddball paradigm was designed to complete one sequence in 3.2 seconds. Therefore, 3 second SSVEP time window was taken as an optimal time window for online SSVEP classification.

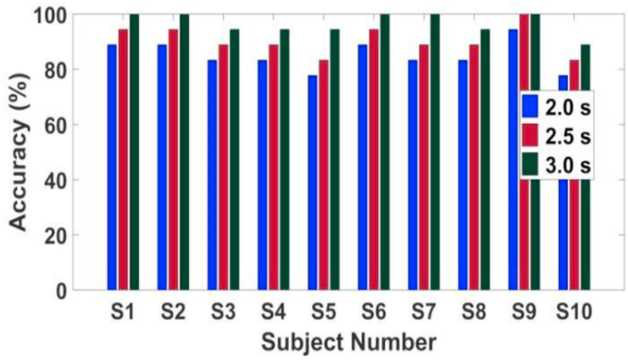
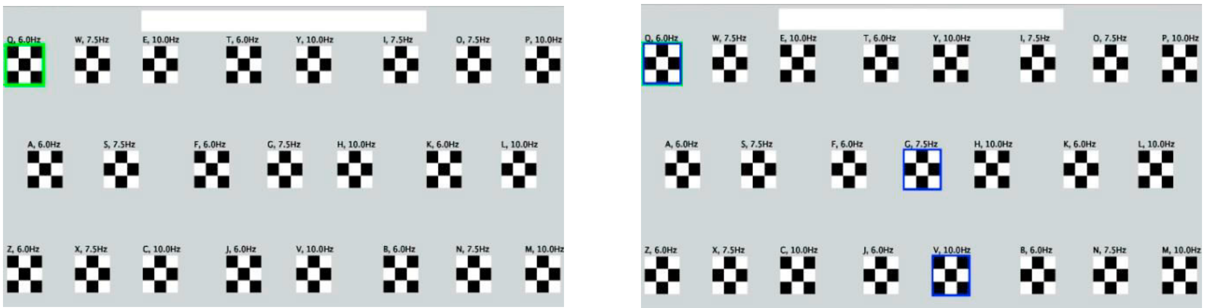


Fig. 6. Offline SSVEP classification accuracy

3.2. Experiment 1: online cue guided SSVEP-EOG system

The optimal SSVEP stimulus time window and features for eye movement detection were calculated for online SSVEP-EOG system. The subjects were asked to perform three sessions of online cue guided experimental procedure. The cue guided program randomly selects the targets from the keyboard layout and subjects were instructed to give attention on the selected targets. An initial offset or rest period of 10 seconds was given at the beginning of the experiment. At the end of an offset period, the cue guided paradigm randomly selects the target character and the corresponding visual stimulus is highlighted with green color shown in Fig. 7. (a). The oddball paradigm starts to highlight the targets during SSVEP stimulation time window. Once the desired target highlight is changed into blue color, the subjects were instructed to perform blink eye movement to synchrony with oddball paradigm shown in Fig. 7. (b). At the end of the SSVEP stimulation time window the EMSI algorithm detects/classifies the desired target frequency. The eye movement detection algorithm detects the blink eye movements and the corresponding time was mapped with oddball paradigm time. The respective target was identified by using recognized SSVEP frequency value and eye blink time. Finally the detected target was displayed in the text box. After SSVEP stimulation time window, a time duration of 0.8 second was given to all the subjects as rest window. Again the same procedure was repeated 22 times as SSVEP stimulation window followed by a rest window. In a single session, the subjects were instructed to type all twenty three target characters as per instruction from the cue guided system. Three sessions of cue guided online analysis were performed on all the subjects. The classification accuracy and information transfer rate of this experiment shown in Fig. 8 and Table 1.



(a) (b)

Fig. 7. Online cue guided paradigm (a) Random selection, (b) Cue-guided system with oddball paradigm

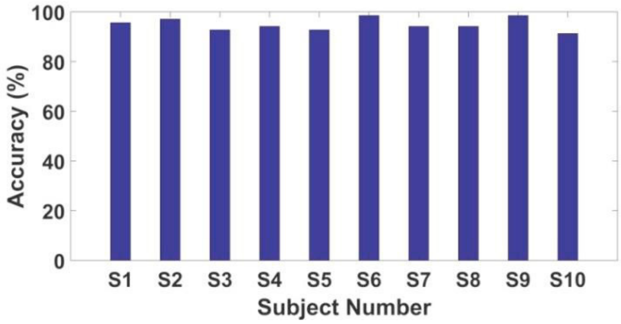


Fig. 8. Classification accuracy of online cue guided system

3.3. Experiment 2: online free spelling task

The experimental procedure is same as online cue guided system. Instead of highlighting single selected target, the online free spelling system highlights all the targets during SSVEP stimulation time window shown in Fig. 4. The oddball paradigm starts to highlight two or three unique frequency valued visual stimuli at a time with blue color in a sequential manner (see Fig. 4). Once the desired target is highlighted with blue color, subjects were asked to perform blink eye movement to synchronize with the highlight. After SSVEP stimulation time window a duration of 0.5 seconds was given as a rest window. In single session the subjects were asked to type 23 characters in any order based on his/her interest. Three sessions of online free spelling tasks were performed by all the subjects for validation. The classification accuracy and information transfer rate (ITR) of the online free spelling task shown in Fig. 9 and Table 1.

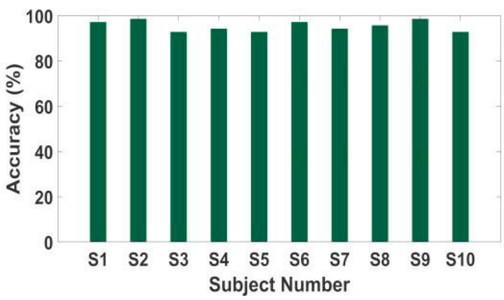


Fig. 9. Classification Accuracy of Online Free Spelling Task

Table 1. ITR of online cue guided and free spelling task experiments.

Subjects Number	Time for both cue and free spelling experiment (in seconds)	ITR of cue-guided system (bits/min)	ITR of free spelling task (bits/min)
S1	3.2	76.34353	78.84421
S2	3.2	78.84421	81.55588
S3	3.2	71.72556	71.72556
S4	3.2	73.982	73.982
S5	3.2	71.72556	71.72556
S6	3.2	81.55588	78.84421
S7	3.2	73.982	73.982
S8	3.2	73.982	76.34353
S9	3.2	81.55588	81.55588
S10	3.2	69.55419	71.72556
Average	3.2	75.32	76.02

3.4. Experiment 3: word spelling/typing task

For word spelling task ten words were chosen/formed from randomly selected twenty three characters. The subjects were asked to spell/type all ten words one by one in any order. The chosen words are BANANA, MANGO, CHEESE, SALT, SWEET, LEMON, APPLE, COFFEE, PAPAYA and LIME. Table 2, illustrates the typing ability of all the subjects using proposed SSVEP-EOG system. The entries in Table 2 illustrates the typos or error made while typing the word. The 100 % spelling accuracy was obtained for four subjects and averaged spelling accuracy across all the subjects is 96.73%. Fig. 10, shows the spelling accuracy of proposed SSVEP-EOG system.

Table 2. Spelling/Typing ability of all the subjects.

Target words	Subject Number									
	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10
BANANA	0	0	0	1	0	0	0	1	0	1
MANGO	0	0	1	0	0	0	0	0	0	1
CHEESE	0	0	0	0	2	0	1	0	0	0
SALT	0	0	0	1	0	0	1	0	0	0
SWEET	0	0	0	0	1	0	0	1	0	1
LEMON	0	0	1	0	0	0	0	0	0	0
APPLE	0	0	0	0	0	0	0	0	0	0
COFFEE	0	0	0	1	1	0	0	0	0	0
PAPAYA	0	0	0	0	0	0	1	0	0	0
LIME	0	0	0	0	0	0	0	0	0	0

Fig. 10. Spelling accuracy of online word spelling task

4. Discussion

The offline and online experiments were performed on all the subjects to validate the proposed system. The paired T-test was performed between the classification accuracies of online cue guided, free spelling and word spelling experiments.

Table 3. ITR comparison between proposed and existing speller systems.

Subjects Number	Time (in s) Proposed System	Time (in s) Dual Frequency System	Time (in s) SSVEP-VOG system	ITR of Proposed SSVEP-EOG System (bits/min)	ITR of Dual Frequency System (bits/min)	ITR of SSVEP-VOG System (bits/min)
S1	3.2	3.5	3.5	78.84421	41.94082	65.57766
S2	3.2	3.5	3.5	81.55588	47.97848	69.7998
S3	3.2	4	4	71.72556	43.36593	57.38045
S4	3.2	4	4	73.982	31.78183	53.96374
S5	3.2	4	4	71.72556	36.69822	55.64335
S6	3.2	3.5	3.5	78.84421	44.9036	67.64069
S7	3.2	4	4	73.982	32.97897	53.96374
S8	3.2	3.5	3.5	76.34353	46.42645	63.5924
S9	3.2	3	3	81.55588	40.80687	78.91414
S10	3.2	4.5	4.5	71.72556	31.49919	47.96777
Average	3.2	3.75	3.75	76.02844	39.83804	61.44437

Test results show that, no significant difference across their mean accuracies ($p<0.001$). To prove the novelty of the present study, the proposed system was compared with other SSVEP based speller systems like dual frequency SSVEP method and SSVEP-VOG method [3,7]. The dual frequency SSVEP and SSVEP-VOG system were designed for evaluating the proposed SSVEP-EOG system. The subjects were tasked to perform three sessions of free spelling task using dual frequency SSVEP and SSVEP-VOG system. The classification accuracy of these three systems were compared and shown in Fig. 11. The paired T-test between proposed and the existing speller system shows significant difference (($p<0.001$, proposed and dual frequency) and ($p<0.01$, proposed and SSVEP-VOG)). The information transfer rate comparison among these three systems were shown in Table 3.

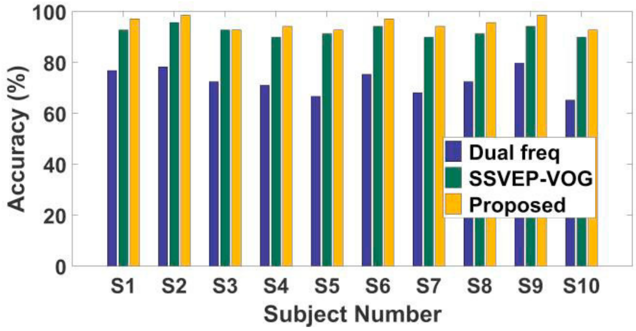


Fig. 11. Classification accuracy comparison between proposed and existing speller systems

From the above results, we can conclude that the proposed SSVEP-EOG system outperforms than existing dual frequency SSVEP and SSVEP-VOG systems.

5. Conclusion

The SSVEP-EOG based hybrid BCI system was designed and different experimental procedures were performed on all the subjects. The conventional SSVEP based spellers have a limitation on the stimulus design. Many researchers have proposed/designed SSVEP speller system with more targets. Those systems have a unique frequency valued visual stimuli and the probability of target classification/identification rate is less. The effective signal processing algorithms are needed for better classification. In this study, we designed simple and high performance SSVEP based speller system with EOG integration. Three visual stimuli were used and the probability of target detection rate is high as compared to other systems. The average classification accuracy and ITR of the proposed system is 96.73% and 76.02 bits/min respectively. The result shows that the proposed system can be easily used as a communication system for disabled people to interact with the world.

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