Design and Implementation of SSVEP based BCI Using a Canonical Correlation Analysis

Mamta Kumari[1], Sunil B. Somani[2]

Abstract— Using steady-state visually evoked potential in brain-computer interface (BCI) system is the subject of a lot of research. SSVEP signals are used as basis for brain-computer interface because of its reliability, high information transfer rate, minimal training and flexibility. Canonical correlation analysis is one of the new emerging method, which seems to have some processing improvement and advantages compared to traditional SSVEP detection method, like better signal to noise ratio (SNR), lower harmonic frequencies, i.e. a series of frequencies which has same fundamental frequencies.

Index Terms— BCI- Brain Computer Interface, EEG-Electroencephalography, SSVEP- Steady State Visual Evoked Potential, SNR- Signal-to-Noise Ratio, CCA- Canonical Correlation Analysis, PSDA-Power spectral Density Analysis,LED-Light Emitting Diode.

.

1 Introduction

THE functionality of the human brain is still relatively unknown, although much effort has been put into revealing its secrets. Advances in cognitive neuroscience and brain imaging technologies have started to provide us with the ability to interface directly with the human brain. This ability is made possible through the use of sensors that can monitor some of the physical processes that occur within the brain that corresponds with the certain form of thought. Researchers have used these technologies to build brain-computer interface (BCI), communication systems that don't depend on brain's normal output pathways of peripheral nerves and muscles. The brain-computer interface (BCI) can be described as a communication link between brain and machine. The BCI is a computer based system that acquires brain signals, analyses them, & translates them into the commands that are relayed to an output devices to carry out a desired action [3]. BCI system have been used to help disabled users by giving back mobility and breaking the isolation of people with physiological disorder and also it opens up new possibilities in human robot interaction for able bodied people. The electroencephalogram (EEG) is a study of brain function that reflects the brain's electrical activity [4]. To collect brain electrical signal using electrodes placed on the scalp, which is added a conductive paste to enable the brain electrical signal, which is of a scale of microvolts, can be recorded and analyzed. SSVEP is generated in the EEG when an external light source with a constant twinkling frequency provokes the visual field. Then the effect would be appeared in the vision region of the brain which is in the occipital lobe. Recording the EEG from that region, one could extract the SSVEP with the same frequency of the external twinkling light source and its harmonics [6]. SSVEP is an EEG signal response to the flickering visual stimulus as a large range of frequencies, from 1 to 90 Hz, but good response are normally acquired among 5 to 27 Hz. Canonical correlation analysis is a type of correlation technique that focuses on two sets of variables. Its strengths is that it tries to find pairs of linear transformations for the two sets such that when the transformations are applied to the new sets of variables have a maximal correlation [7]. Detection methods based on CCA also rely on the fact that a periodic pattern with the same frequency as the stimulus frequency or one of its harmonics can be tracked back in the brain signals. The use of CCA seems to have some promising improvements and advantages compared to traditional methods, like SNR, lower inter-subject variability and the possibilities to use harmonic frequencies. CCA based SSVEP detection methods used in this research don't require any form of training [10]. Since the CCA-based detection method is able to detect different harmonic frequencies, hence especially when the use of harmonic frequencies is desired, the CCA-based detection methods gives the absurd results when the time slot is very small for EEG signal, to overcome from this we can use the band pass filter along with golay filter to get the desired results.

ISSN 2229-5518

• [1] Mamta kumari , Department of Electronics and Telecommunication, M.I.T. College of Engineering,Universit of Pune, India,PH-9665498559. E-mail: Mamtamitm@gmail.com

• [2] Sunil B. Somani, Professor in the Department of Electronics and Telecommunication, M.I.T. College of Engineering, University of Pune, India,PH-9422501556. E-mail: Sunil.somani@mitcoe.edu.in

2 System Architecture

The proposed system uses SSVEP signals of 8Hz, 14Hz and 28 Hz .Through this research project a software and hardware platform is setup to support the BCI applications whose performance could be implemented by signal acquisition, signal processing ,classification , generation of command signals and interfacing with the device.

The system architecture consists of mainly three components as shown in figure 1:-

1) Acquire SSVEP signals and denoising them from noisy oscillators.
2) Extract features from SSVEP signals and Implement automatic detection system using suitable classifier.
3) Generate command signals which can perform predefined tasks and develop a prototype and demonstrate the device interface.

IJSER

2.1 EEG Data Acquisition

The database used in this study is obtained in this study is obtained from the reference of [12]. These signals are in .mat format. This EEG-SSVEP database consists of three databases of 8 Hz, 14 Hz and 28 Hz. Each database has five trials. These signals were recorded using Ag/Agcl electrodes from 128 locations distributed over the entire head using a BIOSEMI EEG system which contain miniature electronics to allow higher EEG signal-to-noise ratio and better sensitivity to weak brain signals. Electrodes were applied to the forehead or behind the ears using head caps, convert the ions current into electrical current and made connection between the scalp and EEG recording device. Electrolyte gel is applied between scalp and the electrodes to prevent attenuation of the signal [1]. Here we are taking the EEG data recording time for EEG is 30 seconds. The SSVEP ONSET point is at second 5 from beginning of the data. The SSVEP OFFSET point is at second 20 from the beginning of the data.

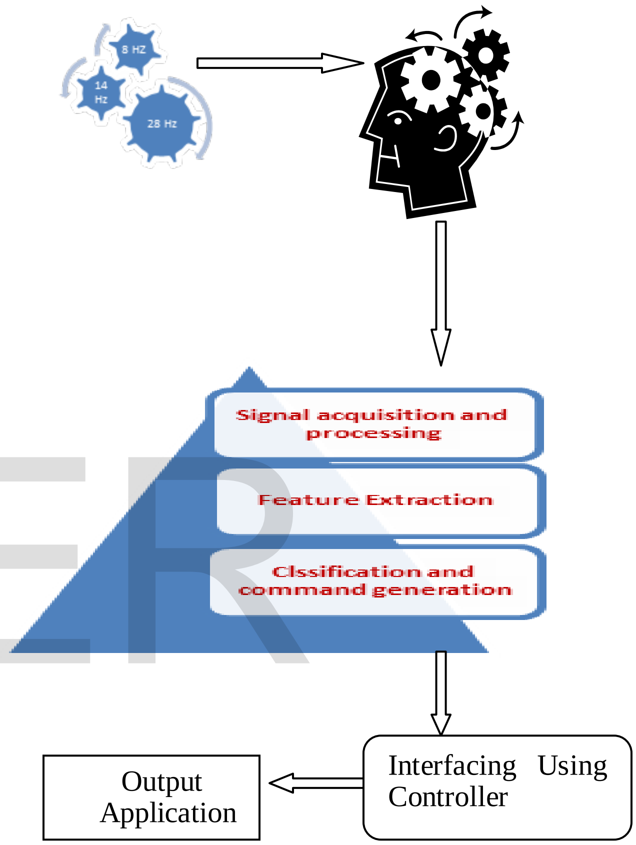

Fig 1: Block Diagram of the system

2.2 Feature Extraction and Classification

In pattern recognition, feature extraction is a special form of dimensionality reduction. When the input data to an algorithm is too large to be processed and it is suspected to be notoriously redundant then the input data will be transformed into a reduced representation set of features is called feature extraction. Transforming the input data into the set of features is called feature extraction. The acquired signals are usually mixed with the noise. The noises are induced due to instrumentation amplifier, poor contact of electrodes, power line interface. Due to these interferences, fundamental frequency and its harmonics may be difficult to

ISSN 2229-5518

recognize hence, filtering is necessary. For this work the second order Savitzy-Golay (SG) filter is used to smooth the signal. SG filter preserves important time-domain features, such as signal extrema and high frequency content. For this system features are extracted using Canonical Correlation Analysis (CCA) method. CCA is a type of correlation technique that focuses on two sets of variables. Its strength is that it tries to find pairs of linear transformations for the two sets such that when the transformations are applied the new sets of variables have a maximum correlation. The detection method based on CCA also rely on the fact that a periodic pattern with the same frequency as the stimulus frequency or one of its harmonics can be traced back in the brain signals. In our method, variables in one set are signals *x* (t), recorded from several channels within a local region and the second set is stimulus signals. Any periodic signal can be decomposed into the fourier series of its harmonics (sin ($2\pi ft$), cos ($2\pi ft$), sin ($4\pi ft$) , …..):

$$Y(t) = \begin{pmatrix} Y_1(t) \\ Y_2(t) \\ Y_3(t) \\ Y_4(t) \end{pmatrix} = \begin{pmatrix} \mathrm{Sin}\,(2\pi ft) \\ \mathrm{Cos}\,(2\pi ft) \\ \mathrm{Sin}\,(4\pi ft) \\ \mathrm{Cos}\,(4\pi ft) \end{pmatrix}$$

The value of t = 1/S , 2/S, ……. T/S.

Where t is the base frequency, T is the number of sampling points, and S is the sampling rate [9].
Now suppose there are K stimulus frequencies $f_1, f_2 \ldots\ldots f_k$ and that the analyzed signal has been acquired from N channels within an L s window. Our recognition is as follows. The stimulus frequency fs satisfies

$$f_s = \max_f \varrho(f), \qquad f = f_1, f_2, \ldots.. f_k .$$

Where $\varrho(f)$ is the CCA coefficient/co-variance of x_{LN} and y.

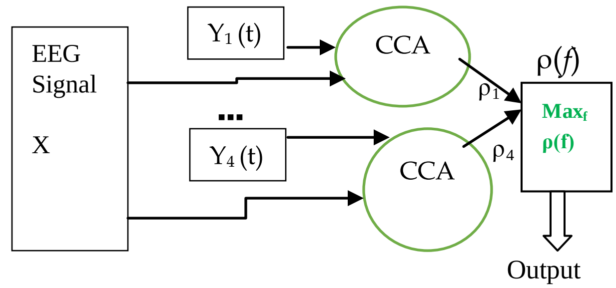

Fig 2: Feature Extracted and Classified by CCA

The detected f_s can be put into the class c for our convenience. Higher the value of CCA co-efficient means higher the information.
The use of CCA seems to have some promising improvements and advantages compared to the traditional PSDA-based detection methods, like better signal-to-noise ratio (SNR), lower inter subject variability and possibility to use harmonics frequencies. The CCA based detection method used in this research don't require any form of training. CCA can also be performed in the case of the decreasing magnitude of higher frequencies or a combination where new set of variables with a maximal correlation is required. CCA method gives the absurd result when the time-slot is very small for EEG signal; to overcome from this we can use the band-pass filter along with the Golay filter to get the desired results.

2.3 Interfacing

The interfacing can be done by controller through serial port which provides a prototype has been developed by using 8051 controller and a DC motor. The results are sent from MATLAB to controller through serial port. Kiel software has been used to program the controller.

3 Implementation and Results

In the first stage of this work reference signals for four subjects were loaded in MATLAB. After that in the second stage the CCA method is used for the feature extraction and classification. In the last stage interfacing is done by using microcontroller IC, a LED display and DC motor.

Phase 1:
Raw SSVEP signal of 8 Hz and 14 Hz

Phase 2:
Now we have to apply CCA method between the stimulus signals and the generated SSVEP signals. Here we will use the 8Hz frequency signal as a

IJSER

target/stimulus frequency and SSVEP signals of 8 Hz signal which is generated. With the help of MATLAB tool we get the CCA co-efficient/co-variance. The CCA method itself extracts the features of SSVEP signals and also classifies it in the term of CCA co-efficient/ co-variance. Higher the value of CCA co-efficient reflects the most information. The CCA co-efficient can be used for Generate command signals which can perform predefined tasks.

Phase 3:
In the last stage of this research work the interfacing is implemented by the using a microcontroller, a LED display and a dc motor; in which the generated command is used as a input signals.

RESULTS:

Subject / one	CCA with reference to signal	Covariance for 8 Hz	Covariance with 14 Hz
Trial 1	8Hz	**0.3714238**	0.1586642
	14Hz	0.1920505	**0.2182768**
Trial 2	8Hz	**0.3756347**	0.1451164
	14Hz	0.1784333	**0.2213296**
Trial 3	8Hz	**0.2877205**	0.1110825
	14Hz	0.1463627	**0.2212236**
Trial4	8Hz	**0.2447987**	0.146500
	14Hz	0.1465964	**0.2216199**
Subject / two	CCA with reference to signal	Covariance for 8 Hz	Covariance with 14 Hz
Trial 1	8Hz	**0.3301264**	0.1626964
	14Hz	0.2323961	**0.3711204**
Trial 2	8Hz	**0.1722747**	0.1059908
	14 Hz	0.1116774	**0.2230239**
Trial 3	8Hz	**0.164342**	0.1185967
	14Hz	0.1592584	**0.1843960**
Trial4	8Hz	**0.1722747**	0.1059908
	14 Hz	0.1434164	**0.2048296**
Subject / three	CCA with reference to signal	Covariance for 8 Hz	Covariance with 14 Hz
Trial 1	8Hz	**0.1722747**	0.1059908
	14Hz	0.1881398	**0.3081135**
Trial 2	8Hz	**0.3960355**	0.1582324
	14Hz	0.2204933	**0.3704779**
Trial 3	8Hz	**0.3989549**	0.1671835
	14Hz	0.2503416	**0.3198515**
Trial 4	8Hz	**0.3331818**	0.1701136
	14Hz	0.2526705	**0.2930063**

Table 1: Result after application of CCA

The results from the above table conclude that the covariance for any signal with same reference signal is approx. 1.8 times higher than the covariance for any signal with different reference signal. Higher the value of covariance means higher the similarity with the reference signal.

4 Conclusion

In this project work the features of SSVEP signals are extracted successfully and classified them with good accuracy by CCA method. After that we have generated control signals from classified data and developed a prototype using a microcontroller as an input data for the desired output applications .It is more user friendly and compatible for working in real time environment. The algorithm is the more efficient, accurate and easy method for processing of EEG signals used as the command for output applications. The use of CCA seems to have some promising improvements and advantages compared to traditional methods, like SNR, lower inter-subject variability and the possibilities to use harmonic frequencies. CCA based SSVEP detection methods used in this research don't require any form of training. Since the CCA-based detection method is able to detect different harmonic frequencies, hence especially when the use of harmonic frequencies is desired.

REFERENCES

[1] A. Nijholt, D.Tan, G. pfurtscheller, C. Brunner, R. M. J.del, B.Graimann, F. popescu, B. Blankertz and K. R.Muller, "Brain-computer interfacing for intelligent system," *IEEE Intell. Syst.* Vol. 23,pp72-79,2008.
[2]. M. Middendorf, G. McMillan, G. Calhoun and K. Jones, "Brain-computer interface," *IEEE Trans. Rehabil. Eng,* vol.8 pp 234-239,2006.
[3] Klaus-Robert Muller, Michael Tangermann, Guido Dornhege, Matthias Krauledat, Gabriet Curio, Benjamin Blankertz, " Machine-learning for real time signal trial EEG-analysis : From brain-computer interfacing to mental state monitoring," published on journal of Neuroscience methods 167(2008), 82-90.
[4] M. Middendorf, G.R. McMillan, G. Calhoun, and K.Jones,"Brain computer interfaces based on steady –state visual –evoked response." *IEEE Trans. Rehab. Eng.*, vol.8, PP 211-314,2000.
[5] Y.J. Wang,R.P. Wang, X.R. Gao,and S.K. Gao " Brain-computer interface based on the high-frequency steady-state visual evoked potential," in proc.2005 *1st Int. Conf. Neural Interface and Control ," Wuhan, China: IEEE* 2005, pp-37-39.
[6] G.R. muller-Putz, R. Scherer, C. Braunels, and G. Pfurtscheller, "Steady-State Visual Evoked potential (SSVEP)-based communication: impact of harmonic frequency component." *J. Neural Eng.*, vol. 2, pp. 123-130, 2005.

IJSER

[7] G. Bin, X. Gao, Z. Yan,B. Hong, and S. Gao,"An online multi-channel SSVEP-based brain-computer interface using a canonical correlation analysis method, Journal of Neural Engineering, 6 (2009), p.046002.

[8] D. Clark, "Understanding canonical correlation analysis," no. 3 in *concepts and techniques in modern geography*, Geo abstracts Ltd, 1975.

[9] Z. Lin, C. Zhang , W. Wu, and X. Gao " Frequency recognition based on canonical correlation analysis for SSVEP-based BCIs," *IEEE Transactions on Biomedical Engineering* 53 (2006), pp. 2610-2614.

[10] Y. Zhang, G. Zhou, Q. Zhao, A. Onishi, J. Jin, X. Wang, and A. Cichoki, "Multiway canonical correlation analysis for frequency omponents recognition in SSVEP-Based BCIs," *In: 18th Int'I Conf. on Neural Information Processing (ICONIP2011)*,pp. 287-295, 2011.

[11] A. Nielsen, "Multiset canonical correlations analysis and multispectral, truly multiemporal remote sensing data," *IEEE Trans. on Image process*, vol. 11, no. 3, pp.293-305,2002.

[12]www.bakardjian.com.

IJSER