ISSN(Online): 2320-9801
ISSN (Print): 2320-9798

International Journal of Innovative Research in Computer and Communication Engineering

(An ISO 3297: 2007 Certified Organization)

Vol. 4, Issue 9, September 2016

Brain-Computer-Interface: A Neurotechnological Survey on Brain's Signal Preprocessing Techniques

Brijesh K. Soni[*1], Deepak Mishra[2], Gauri Richharia[3], Mirza Samiulla Beg[4]

Assistant Professor, Department of Computer Application, AKS University, Satna, MP, India[1*]

Assistant Professor, Department of Bio-Technology, AKS University, Satna, MP, India[2]

Assistant Professor, Department of Electrical Engineering, AKS University, Satna, MP, India[3]

Teaching Associate, Department of Computer Application, AKS University, Satna, MP, India[4]

ABSTRACT: This survey article addresses to the various consecutive steps of techniques for brain signal preprocessing activity. Whole signal preprocessing activity can be grouped into three categories as signal referencing, temporal filtering and signal enhancement. In the first part we discussed various signal referencing techniques such as average reference, common reference, and current source density, the second part is written about temporal filtering of brain signal and the final part where we focused specially about various signal enhancement techniques such as independent component analysis, principal component analysis, common average referencing, common spatial patterns and surface laplacian.

KEYWORDS: Reference Site, Multivariate Data Set, Finite Impulse Response, Surface Potential, Gaussian Form.

I. INTRODUCTION

An interdisciplinary innovative survey in Bio-Medical-Technology clarified by [1] that the procedure of signals processing needs artifacts reduction and quality enhancement of activity potentials. However, signal preprocessing attempts to increase signal-to-noise-ratio. Signal-to-noise ratio is abbreviated by [2] scientists as SNR, which means the dimensionless ratio of signal power to noise power contained in recorded activity potential. The SNR parameterizes the performance of optimal signal processing, when the noise is Gaussian form. SNR is defined [3] as the ratio of the power of a signal which is meaningful information and the power of background noise which is artifact:

$$SNR = \frac{\boldsymbol{Psignal}}{\boldsymbol{Pnoise}}$$

In above equation *P* is an average power. Given signal power and noise power both must be measured at the equivalent points in a system, and within the same system signal bandwidth.

Historical studies shows that, in the 1940 Claude Shannon [4] developed the idea of channel capacity, by focusing on the concept of Harry Nyquist and Ralph Hartley regarding information theory, and then formulated a complete theory of information and its transmission and this is known as Shannon–Hartley theorem. Shannon–Hartley theorem represents the maximum rate at which signal can be transmitted over a communications channel of an associated bandwidth having noise signal. This theory expresses Shannon's channel capacity for a communication system. A bound on the maximum amount of error free information per time unit that can be transmitted with a associated bandwidth in the presence of the noise artifact, assuming that the recorded signal potential is bounded, and that the Gaussian noise process is characterized by a known power or power spectral density.

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II. RELATED WORK

The fundamental idea of this article emerged from [5] the review article; consist of most of the techniques discussed here, as referencing, temporal filtering and signal enhancement, but with some limited explanation. These techniques are explored in this article with graphical classification. Another article [6] also published signal enhancements techniques as independent component analysis, common average referencing, surface laplacian, principal components analysis, and common spatial pattern, which are detailed and more crystal clear presented in this article with the help of suitable visual classification.

III. SIGNAL PREPROCESSING STEPS

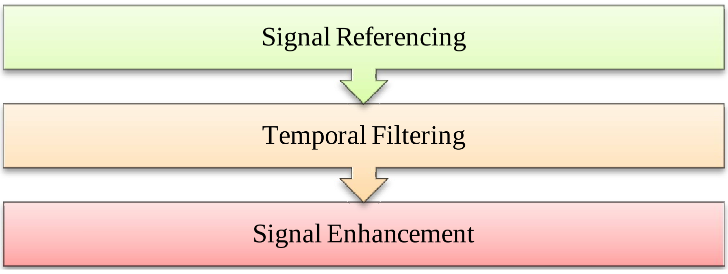

Fig.1. Signal Preprocessing Steps

Signal Referencing [SR]

EEG signals from the scalp are obtained using, different electrodes on different positions. Activity voltage to be measured by a given specific electrode is a relative measure; the measurement may be compared to another voltage placed on another reference site. This shows combination of, brain activity at the reference site and noise, at the given electrode. So the reference site to be chosen where the brain activity is almost zero. Generally the nose, mastoids and earlobes are used as reference site. Various signal referencing techniques are listed in fig.2.

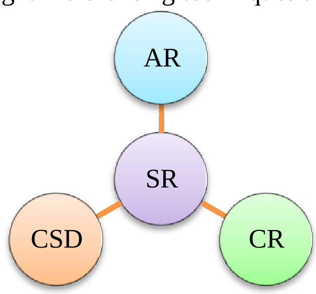

Fig.2. Techniques for Signal Referencing

A. AVERAGE REFERENCE [AR]:

Researchers [7] published that AR technique is used to subtract the average of the activity at all electrodes from the measurements. This technique works on the principle that the activity at the whole head at every moment sums up to zero. Therefore, the average of all activity shows an approximate of the activity at the reference site. Subtracting this average produces in principle a dereferenced solution. However, the corresponding low density of the electrodes and the fact that the lower part of the head is not considered, bring some practical problems along.

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B. COMMON REFERENCE [CR]:

Researchers [8] published that CR technique is uses one common reference for all electrodes. Generally the site of reference is situated at long distance from all ground electrodes. The activity at the reference site electrode influences all measurements equally, and differences between electrode measurements still hold all information needed.

C. CURRENT SOURCE DENSITY [CSD]:

Researchers [9] published that CSD is the rate of changing in current flowing through the scalp surface". This quantitative value can be derived from EEG signal, and it may be measured as the potential difference between an electrode and a approximated weight of their surrounding electrodes. The CSD can be approximated by computing the laplacian of EEG data. Laplacian evaluate the summation of the differences between an electrode and its neighbor's electrodes. There is problem with this estimation is that it is valid only, when the electrodes are distributed in a two dimensional plane and also equally distant.

Temporal Filtering [TF]

Temporal filtering used to remove or attenuate frequencies within the raw signal that are not of interest. This can substantially improve the signal-to-noise ratio. The main activity is to decide which frequencies are of interest and which are noise. Temporal filtering is based on the Fourier Transform technique where any series of data can be measured as a linear sum of sine waves of different frequencies. The brain signals are naturally polluted by many internal and external noises. Noise can be removed using simple filters. Generally the applicable information in BCIs is found in the frequencies less than 30Hz. So noise with higher frequencies can be eliminated by using Finite Impulse Response low pass filter. Various temporal filtering techniques are listed in fig.3.

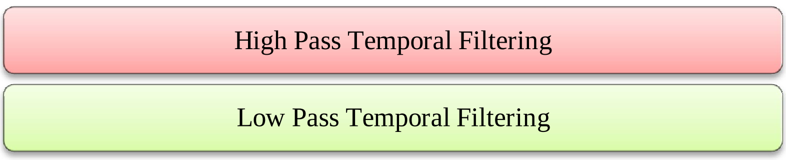

Fig.3. Techniques for Temporal Filtering

A. HIGH-PASS TEMPORAL FILTERING [HPTF]:

Technical literature [10] described that HPTF is a process in which signals to be passed with higher frequency than a certain cutoff frequency and attenuates signals with frequencies lower than the cutoff frequency. The amount of attenuation for each frequency depends on the filter design. It is also referred as low cut filtering or bass cut filtering. HPTF uses a local fit of a straight line to remove low frequency artifacts. This is preferable to sharp roll off FIR oriented filtering as it does not introduce autocorrelations into the data.

B. LOW-PASS TEMPORAL FILTERING [LPTF]:

Technical literature [11] described that LPTF is a process in which signals to be passed with lower frequency than a certain cutoff frequency and attenuates signals with frequencies higher than the cutoff frequency. It is used to removes high frequency noise but also reduces the strength of the signal of interest, particularly for single event experiments. By default, the temporal filtering that is applied to the data will also be applied to the model.

Signal Enhancement [SE]

The option of a suitable signal enhancement technique is dependent on many factors such as the signal recording technology, number of electrodes, and neural mechanism of the BCI. We describe here briefly only five methods which are the most applied in BCI designs. Various signal enhancement techniques are listed in fig.4.

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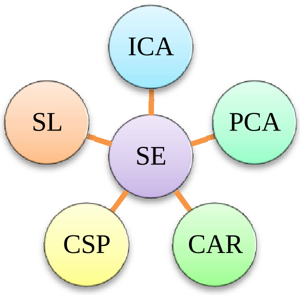

Fig.4. Techniques for Signal Enhancement

A. *INDEPENDENT COMPONENT ANALYSIS [ICA]:*

Studied survey [12] focuses that ICA technique attempts to decompose multivariate signal components into independent Non-Gaussian signals. It is a computational technique for separating multivariate signal components into additive subcomponents. Like the mutual statistical independence of the Non-Gaussian type source signals, when the statistical independence assumption is correct, blind ICA separation of a mixed signal gives good results. ICA separates the artifacts from the EEG signals into independent components that are based on the characteristics of the data without depending on the reference channels. ICA technique decomposes the multi channel EEG data into temporal independent and spatial fixed components. The data in [13] the recorded samples, each channel data and the frontal data are also maintained during the ICA artifact removal. ICA is computationally efficient but requires more computations to decompose signals. However it is particularly efficient when the EEG and the artifacts have comparable amplitudes. ICA represents high performance when the size of the data to decompose is large.

B. *PRINCIPAL COMPONENT ANALYSIS [PCA]:*

Studied survey [14] focuses that PCA is a technique that transforms correlated vectors into linearly uncorrelated vectors known as principal components. It depends on decomposition of covariance matrix. This is a classical method of second order statistics. The PCA is performing well but it is not as well as ICA. First principal component explains as much of the variability in the data as possible, and every succeeding principal component explain for as much of the resting variability as possible, and must be orthogonal to the first component. The PCA analysis [15] visualize the internal structure of the data in a way which is best explains the variance in the data. In a case a multivariate dataset is visualized as a set of coordinates in to a high dimensional data space, ICA supplies the user with a lower dimensional data space representation. PCA helps in reduction of feature dimensions. Ranking will be also done by using PCA based on the variability of the signal properties, helps in classification of the data.

C. COMMON AVERAGE REFERENCING [CAR]:

Studied survey [16] focuses that CAR is a reference-free recording technique that is a solution to the problem of the reference electrode. CAR involves recording technique in bipolar manner from a number of electrodes, all referred to a single site electrode. CAR technique removes the noise by subtracting the commonly activity from the position of interest. One electrode then calculates the grand mean of EEG signals, by averaging across electrodes, and subtracts the result point wise from the EEG recorded at each electrode. Brain's electrical activity recorded by the reference electrode is theoretically of equal magnitude in the mean and individual electrode signal. In [17] CAR method the removal of mean of all electrodes from all the electrodes results in noise free signals. The effect of the reference electrode should be eliminated from each recording electrode's output when the common average of signal is subtracted.

D. COMMON SPATIAL PATTERNS [CSP]:

Studied survey [18] focuses that CSP is a technique used to find the common projection matrix that decomposes the different classes of single trial EEG datasets. This kind of projection matrix maximizes the differences between the classes, and demonstrated the efficiency of the CSP technique for real time EEG signal analysis. It is accomplished that only parameters that must be accommodated for the CSP are the time moment for the calculation of the CSP and, during on line processing, the time window for the calculation of the variances. So we can say that CSP performs

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transformation of EEG signal into a variance matrix that frequently discriminates between different classes. However the selection of these parameters is not very critical. CSP technique is very careful to artifacts; a single trial containing, such as a movement artifact can cause severe changes in the CSP. The fact [19] is the sample covariance, which is used to estimate the covariance for the determining of the spatial filters. While on line process of the BCI the spatial filters perform a weighted spatial averaging of the EEG, and this reduces the impact of artifacts. CSP technique requires almost identical electrode positions for all trials and sessions which may be difficult to accomplish. For long duration intimation to analyze the EEG data in real time, EEG data of some sessions can be used for the determining of the CSP. CSP does not require a priori selection of subject specific frequency bands and knowledge of these frequency bands and requires use of many electrodes. During the training process the identical electrode positions is to be managed to capture the same signals.

E. *SURFACE LAPLACIAN [SL]:*

Studied survey [20] focuses that SL technique filters out spatially broad features of surface potential also we can say that SL is a technique for viewing the EEG data with high spatial resolution. So conceptually the SL is the second order spatial derivative of the surface potential of scalp. One of the main characteristics of the surface Laplacian is that it is reference free. In SL analysis source and sinks of electrical activity at the level of the skull surface. Due to its coherent spatial high-pass filtering characteristics, the SL can minimize the volume conduction effect, which is important for connectivity analysis. SL improves topographical localization of potential source. An estimate of current density entering or leaving the scalp through the skull is called as the Surface Laplacian of the skull. It only considers the outer shape of the volume conductor and no need of any details of volume conduction. SL [20] is robust against artifacts generated at uncovered regions by the electrode embedded cap and it solves the electrode reference problem. Vision movements can be efficiently removed during the signal acquisition in this technique.

IV. CONCLUSION

The literature review [22] showed that signal pre-processing algorithms have been used for EEG based BCIs but no signal enhancement algorithms have been applied on ECoG based BCIs. Only PCA has been used in both groups, and spatial filtering including referencing CAR and SL techniques; and CSP are among the most used techniques that have become increasingly popular in EEG based BCIs. ICA technique decomposes signals potentials into temporal independent and spatial fixed components; it requires more computations for decomposition but computationally efficient. This technique shows high performance for large sized data but can't be applicable for under determined cases. PCA technique helps in reduction of feature dimensions and also helps in classification of data. CAR technique provides improved SNR and in this technique finite sample density and incomplete head coverage cause problems in calculating averages. CSP technique requires use of many electrodes and change in position of electrode may affect classification accuracies, it doesn't require a priori selection of sub specific bands and knowledge of these bands. SL technique is robust against the artifacts generated at regions that are not covered under electrode embedded cap, it solves electrode referencing problem.

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BIOGRAPHY

Mr. Brijesh K. Soni is an Assistant Professor in Computer Application Department, AKS University Satna MP India. He received Bachelor of Computer Application degree in 2010 from APS University Rewa, MP, India, and Master of Computer Application degree in 2014 from GGSIP University of New Delhi, India, and he also qualified the National Eligibility Test for Lectureship conducted by University Grant Commission. His research area is Brain-Computer-Interface. He had completed one research project (Brain-Computer-Interface: Optogenetics-Neurotechnology) and one software project (University Research Administration System). He has also published two research articles in international journals.

Dr. Deepak Mishra is an Assistant Professor in Biotechnology Department, AKS University Satna MP India. He received Bachelor of Science (HONS.) in Chemistry degree in 2005 from APS University Rewa, MP, India, and Master of Science in Biotechnology degree in 2007 from Punjab Technical University of Jalandhar Punjab. India, He also qualified GATE in Biotechnology Discipline in 2011 and Ph.D. in Biotech from APS University Rewa. His research area is Plant Biotechnology, Molecular Biology & Neurotechnology. He had guided different project / Dissertation student. At present he has guiding four Ph.D. scholars. He has also published one book chapter and more than 15 articles in national and international journals.

Miss Gauri Richharia is an Assistant Professor in Electrical Engineering Department, AKS University Satna MP, India. She received Bachelor of Engineering degree (Electronics & Communication Engineering) in 2010 from RGTU Bhopal MP, India, and Master of Technology (Electronics & Control Engineering) in 2012 from SRM University Chennai TN, India.

Mr. Mirza Samiulla Beg is a Teaching Associate in Computer Application Department, AKS University Satna MP India. He received Bachelor of Science(CA) in 2005 from R.D. V. V. Jabalpur, MP, India, and Master of Computer Application degree in 2009 from R.G.T.U of Bhopal (M.P.), India. His research area is Brain-Computer-Interface. He had also published one research articles in international journals.