Abstract

Understanding how human brain works is the most challenging and also one of the most fundamental issues of concern in biomedical signal processing. The issue has been addressed in the literature in a very wide variety of ways. Since it has been found that different regions of the brain are responsible for processing different kind of information, any brain activity is characterized by intra as well as inter regions dynamics. While a multi variate approach to process EEG can help in modeling intra region dependence, the graph theoretic approach can effectively capture inter region interactions. We conjecture that different activities or states of the brain corresponds to different interaction patterns of brain regions. This study is an attempt to understand the static as well as dynamic functional connectivity of the brain using graph theoretic approach in a variety of applications.

Firstly, we hypothesize that presenting different types of stimuli to the brain will stimulate different kinds of brain interactions. In order to validate this hypothesis, we first explore the static functional brain networks in the context of face recognition process. We speculate that face recognition under different scenarios may involve different kind of brain interactions. For example, if we present positive faces which are easy to recognise, there should be lesser frontal lobe activation in comparison to negative faces which are difficult to recognise and require critical thinking. So it seemed logical that graph theoretic approach would be best suited to capture these interactions. In order to accomplish this, we used EEG signals as they are most easy to obtain and also in a non intrusive way. To understand the underlying process of face recognition, one of the most widely used approaches is to study the facial features, in particular, ordinal contrast relations around the eye region, which plays a crucial role in face recognition. In our work, we investigate graph theoretic approaches to know the importance of contrast features around the eye region in face recognition. In this endeavour, we studied functional brain networks, formed using EEG responses, corresponding to four types

of visual stimuli with varying contrast relationships: positive faces, contrast chimeric faces (complete photo-negated faces, preserving the polarity of contrast relationships around eyes), contrast negated faces and only eyes. We observed the variations in brain networks for each type of stimuli by finding the distribution of graph distances across brain networks of all subjects. In addition to that, our statistical analysis shows that positive and chimeric faces are equally easy to recognize in comparison to negative faces and only eyes where the comparison is difficult. The findings suggest that polarity of contrast relationships around eyes plays a significant role in recognizing faces. Moreover, we have also observed higher connectivity in frontal lobe region of the brain networks corresponding to negative faces and only eyes in contrast to positive and chimeric face. It can be due to increased cognitive requirements in the former case where the recognition is difficult.

Since EEG is a non-stationary signal, change in the brain states would be apparently dynamic in nature. We conjecture that different brain states corresponds to different types of static brain networks. If the brain state changes, the corresponding static brain network will also change. In an endeavour to capture the dynamic behaviour of brain networks, we tried to address another well known problem in the field of brain computer interface which is tracking the transitions of brain states. Machine learning based approaches for classification of brain activities do not reveal the underlying dynamics of the human brain. Although principal component analysis helps in finding the dominant eigenvectors which represent the directions of maximum variance for signal representation, we dwell deep into the eigenvectors corresponding to smaller eigenvalues. We conjecture that eigenvectors corresponding to smaller eigenvalues, which represent the directions of lesser variance, would have the invariant information and hence termed them as invariant eigenvectors. In our study, we hypothesize that change in the brain states would manifest in the form of changes in invariant spaces spanned by invariant eigenvectors. Based on this, our first approach is to track the brain state transitions by analysing invariant space variations over time. Our first approach did not account for eigenvalues that signify the amount of variance along invariant eigenvectors. Therefore we propose another algorithm to track the transitions by analysing sub-band characteristic response vector formed using eigenvalues along with the invariant eigenvectors to capture the dynamics. We have taken two real time EEG datasets to demonstrate the efficacy of proposed approaches. It has been observed that in case of unimodal experiment involving only one type of stimuli, invariant spaces explicitly show the transitions of brain states. Whereas sub-band characteristic response vector approach gives better performance in case of cross-modal conditions comprising more than one type of stimuli. Evolution of invariant spaces along with the eigenvalues may help in understanding and tracking the brain state transitions. The proposed approaches can track the activity transitions in real time. They do not require any training dataset.

In general, there are many non unique ways in which brain networks can be formed. Construction of the brain networks should depend on the physics of the underlying problem. In this direction, we have explored the most naturally formed dynamic brain networks in detecting real time seizure onset which has been an active area of research in the study of epilepsy. The detection of epileptic seizures require monitoring of EEG signals for long duration. However, the manual processing of long EEG signals is a very tedious and time-consuming task. Additionally, the recorded EEG signals may be contaminated with various artifacts which can result in erroneous seizure detection. Therefore, an automated patient-specific seizure onset detection is very critical for monitoring and therapy of the epileptic patients in real time, failure at which may lead to life-threatening outcomes. Electroencephalography (EEG) measurements are widely used in seizure detection due to their high temporal resolution, cost effective and non-invasive nature. Various approaches based on machine learning are used for epileptic seizure detection but these approaches don't explicitly reveal the underlying dynamics, require larger datasets for training and are computationally demanding. Although high frequency oscillations are the new biomarkers of epilepsy but they can't be used with existing data acquisition systems as they require high sampling rates and high cut off frequency of the used filters. To overcome the above limitations, we presented a novel approach for real time seizure detection using high spatial frequencies. Since eigenvalues of the graph Laplacian represent spatial frequencies, we conjecture that higher eigenvalues and the corresponding eigenvectors will contain the detailed information of seizure and non-seizure brain states. Hence we formed sub-band characteristic response vector (sub-band CRV) using weighted sum of eigenvectors corresponding to higher spatial frequencies and analysed it over time. We have used a publicly available dataset to demonstrate the efficacy of proposed approach. We observed that the proposed approach performs satisfactorily well in real time automated seizure detection without requiring any kind of prior training. Moreover, our approach is not only accurate in seizure detection but is also independent of sampling rates, hence can be implemented easily in clinical realm for developing an automated seizure detection tool with the existing data acquisition systems operating at low sampling rates.

It can be noted from the above discussion that the used connectivity measure and the selection of eigenvectors play an important role in detecting the transitions of brain states. Based on our observations in the previous problems, we also propose a novel graph distance measure in order to find the degree of similarity between any two networks. We have conducted several experiments to show the efficacy of the proposed graph distance measure. Our results clearly show that the proposed graph distance outperforms the existing graph distances.