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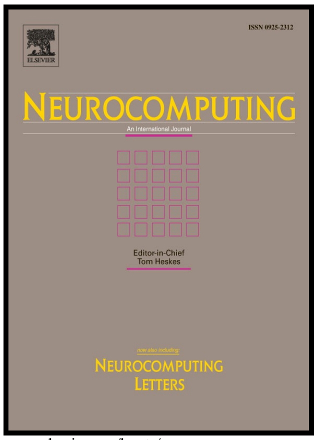

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Assessment of driving fatigue based on intra/inter-region phase synchronization

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Abstract

Driver fatigue has been under more attention as it is a main cause of traffic accidents. This paper proposed a method which utilized the inter/intra-region phase synchronization and functional units(FUs) to explore whether EEG synchronization changes from the alert state to the fatigue state. Mean phase coherence (MPC) is adopted as a measure for the phase synchronization. In order to find spatial-frequency features associated with mental state, we studied the intra/inter-region phase synchronization of EEG in different frequencies. The major finding is that EEG synchronizations in delta and alpha bands in frontal and parietal lobe are significantly increased as the mental state of the driver shifted from alertness to fatigue. This finding is simultaneously validated by NASA-Task Load Index (TLX) and Karolinska sleepiness scale (KSS). The statistical analysis results suggest MPC may be used to distinguish between alert and fatigue state of mind. In addition, the another contribution of the work indicates a simple and significant spatial-frequency pair of electrodes, i.e., Fz-Oz in delta band, to evaluate driver fatigue. It helps to implement real-world applications with wearable EEG equipment.

Keywords: Driver Fatigue; EEG; Mean Phase Coherence; Phase Synchronization; Functional Unit

1 INTRODUCTION

Driver fatigue is a complex state due to a long period of driving and consumption of physical and mental resources, which impairs performance of perception, recognition and vehicle control abilities[1]. The increasing number of traffic accidents due to driver fatigue has become a serious problem in the society. Thus, it is important to develop a system for accurate detection of driver fatigue in real time and reduce accidents by taking corresponding actions, e.g. informing and warning the driver accordingly.

Brain activity and heart rate have been used to monitor operator cognitive workload, including mental fatigue[2-4]. Considerable methods based on physiological variables like Electroencephalogram (EEG), Electrooculogram (EOG), Electromyogram (EMG), Electrocardiogram (ECG) have been proposed to estimate drowsiness[5-8]. Among these physiological indicators, EEG may be one of the most predictive and reliable indicators because it is closely associated with mental and physical activities[1]. A number of methods have been reported in literatures for detecting fatigue by EEG signal. Jap et al. used EEG spectral components to assess 4 algorithms of detecting fatigue, and they demonstrated that the ratio of the total spectra power in theta and alpha bands to the power in beta band showed a larger increase over time[9]. Some research showed that EEG alpha spindle parameters increase fatigue detection both in terms of sensitivity and specificity as compared to EEG alpha-band power[10]. Kar et al. presented a method based on 5 kinds of EEG entropy to quantify fatigue during driving[11]. Moreover, Khushaba et al. developed an efficient fuzzy mutual-information (MI)-based wavelet packet transform feature-extraction method for classifying the driver drowsiness state into 5 predefined drowsiness levels[12].

Most of the existing methods are based on power, spectral power or energy entropy. And in essence, they are amplitude related approaches and their performances are easily affected by EEG amplitude. While Phase Synchronization(PS) analysis can detect interaction of signal pairs by only examining the relationship of instantaneous phase between signals but nothing to do with their amplitudes[13, 14]. PS analysis has also been demonstrated to be important and effective in inferring neural connectivity[15]. Hence, it has been extensively applied to a wide range of neuroscience research[16], such as cortical synchrony networks broke down by infarct[17], comparison between mental rotation tasks and rest[18], and action monitoring and cognitive control[19]. Thus the notion of phase synchronization seems to be an important mechanism for neuronal information processing within a brain region as well as communication between different brain regions[20, 21]. In this point of view, it may reveal more information about fatigue by studying the phase synchronization between different cortical areas.

Some studies have applied PS analysis to fatigue or sleep. In Acharya's work[22], PS based weighted networks was employed to