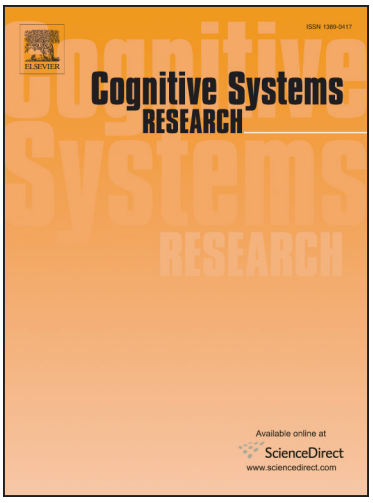

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Electroencephalography based fatigue detection using a novel feature fusion and extreme learning machine

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Abstract

The unsafe behaviors of operators in fatigue state not only lead to declines of work efficiency but also higher error rates and more injuries and even deaths. Automated fatigue detection using Electroencephalogram (EEG) due to helping us decline the occurrence probability of related accidents has gained more and more attention in recent years. Hence, designing a suitable feature extraction approach and choosing an efficient classification methodology are considered as the key to successful implementation. We first propose a new minimum spanning tree (MST) feature extraction approach on the basis of the phase coherence (PC) and a power spectrum density (PSD) method, respectively. Then to further improve the detection performance, we perform feature fusion (FBN-PSD-FF), where the functional brain network (FBN)-based feature characterizing the relationship between brain network organization and fatigue and PSD-based feature characterizing the relationship between power variation and fatigue. Furthermore, an automated fatigue detection system has been developed, which is integrated between the novel fusion feature (FBN-PSD-FF) and extreme learning machine (ELM). Finally, a driving simulation experiment is designed and conducted to demonstrate the proposed detection system, and the Karolinska Sleepiness Scale (KSS) and the Stanford Sleepiness Scale (SSS) are employed to validate the results. Experimental results indicate that the proposed method gives a sensitivity of 95.71%, a specificity of 94.29%, an accuracy of 95.00%, and a highest value of area under the receiver operating curve (AUC-ROC=0.98). The ELM is employed for fatigue detection, reducing the time consuming greatly. Our proposed system can be a viable solution for detecting operators' fatigue and has great potential to reduce fatigue-related crashes in many circumstances such as navigation, driving, aviation, construction industry, etc.

Keywords: Electroencephalography; fatigue detection; Functional brain network; power spectrum density; Extreme learning machine

1 Introduction

Fatigue is one of the crucial factors resulting in lower productivity, poor quality of work, increases accidents in the construction industry and causes crashes in the transportation industry (Aryal *et al.* 2017, Chen *et al.* 2017). Based on a report released in 2015, the non-fatal injury rate in construction industry, induced by fatigue was 10.6 per 10000 workers (Aryal *et al.* 2017). Usually, construction workers perform a large number of heavy tasks under harsh environmental conditions, which are likely to result in fatigue (Cheng *et al.* 2013).especially, in cold and hot environmental temperatures, physical fatigue not only leads to higher error rates but also more work-related injuries (Rowlinson *et al.* 2014). For the transportation industry, fatigue driving is a leading factor in road accidents which results in serious injuries and fatalities (Michalaki *et al.* 2015, Chai *et al.* 2017, Saxby *et al.* 2017). Driver-related fatigue has been defined as feeling tired and less alert while driving (Chen and Xie 2014). With the ever-growing car owners on the road