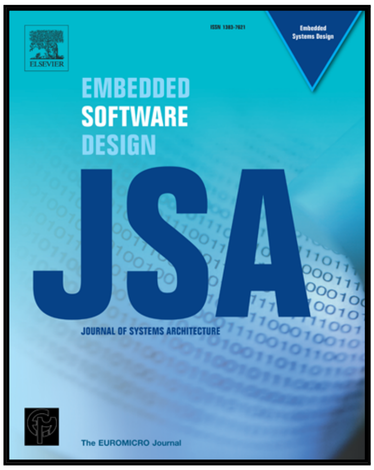


# A Multiplayer Online Car Racing Virtual-Reality Game based on Internet of Brains

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# A Multiplayer Online Car Racing Virtual-Reality Game based on Internet of Brains

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***Abstract*—Development of brain-computer interface (BCI)-controlled virtual reality (VR) games has received increasing attention. Yet, the up-to-date BCI-VR systems were still based on one single BCI and a virtual environment (VE). In this paper, we propose and implement a novel BCI-controlled VR (BCI-VR) game based on a structure of internet of brains (IoB) allowing multiple players from different sites to play a car racing game online. Electroencephalographic (EEG) and electromyographic (EMG) signals from different sites' BCIs are uploaded to a high-performance cloud server where the car-controlled algorithms are performed. During the online car racing period, the players mentally control the speeds of their chosen cars by means of concentration, and the concentration level can be adjusted by performing a mental arithmetic (MA) task with different levels of difficulty. Two linear and two nonlinear EEG features, including theta band power (BP), beta BP, Higuchi's fractal dimension (HFD), and Katz's FD (KFD), are used to transform the concentration level to speeds of four different cars. The players can also sensitively trigger the car in the VE to jump by performing a slight teeth-gritting task to generate easy-to-detect EMG signals. Six subjects participated in this study to test the performance of the proposed hybrid (EEG plus EMG) BCI-VR car racing game. The results indicate that theta BP and HFD are more sensitive to the MA-induced concentration in comparison with beta BP and KFD. Through the test of online car racing game, the results also demonstrated the feasibility that different players play the game in the same VE through multiple BCI control at different sites. More importantly, our BCI-VR implementation has a high usability (only two electrodes are required; calibration needs only 64 seconds) and high feasibility (high average scores of the control, sensory, and distraction factors in a 30-item post-experimental presence questionnaire).**

***Index Terms*—brain-computer interface, virtual reality, EEG, mental arithmetic, concentration, car racing game**

## I. Introduction

BRAIN-COMPUTER INTERFACE (BCI) is a novel neuro-pathway to help people with severe motor-neuron degeneration disease, e.g., amyotrophic lateral sclerosis (ALS), to interact with outer environment or control devices/prosthesis [1]-[2]. It has also been proven a useful tool for detecting mental disorder (e.g., major depression disorder MDD [3]-[4]) and monitoring the affective states of individuals [5]. With the rapid development of virtual reality (VR) technique, the combination of BCI and VR (BCI-VR) has also received increasing attention in both BCI and VR communities.

BCI has been recognized as a novel input device that may change the way to interact with virtual environments (VEs) in the VR community [6]. In the BCI community, the VR is considered a novel feedback modality for BCIs and a safe test bed to provide subjects with the opportunity to train and test the BCI applications before using them in reality [7]. Many BCI-VR applications have been proposed, and most of which are based on two types of BCIs: active and reactive. In an active BCI-VR system, the way for the user to interact with VEs relies on his/her electroencephalography (EEG) features induced by actively modulating the brain activity [7]-[11]. For example, Leeb *et al.* [7] showed that it is possible to use an EEG sensorimotor rhythm (SMR)-based BCI to control a penguin in a projection display-based VE (i.e., CAVE VR), where the SMR feature at the vertex was induced by actively performing a foot motor imagery. Reactive BCI-VR utilizes the brain signals (e.g., P300 [1], SSVEP [12], motion-onset VEP [13]) elicited by external stimuli to control objects in VEs [14]-[16], where VR plays the role of stimulus generation and feedback.

State-of-the-art BCI-VR technologies have shown the feasibility of developing a safe BCI-VR training platform or designing interactive BCI-VR games (see [17] for a review). However, all the previous demonstrations were only based on the combination of a single BCI (i.e., single PC) and a VE. Instead, an internet online game (refers to that many users play the same game through internet) would be more interesting, attractive, and exciting than a single PC game, because the opponents he/she is interacting with are no longer avatars generated by computer programs but real persons distributing at different sites. Moreover, different opponents may have different gaming strategies and capabilities, which better motivate the player to play the online game to challenge others. However, no studies have ever tested the feasibility of BCI-controlled online VR games in which players at different sites play the same VE game using their brain activity. In this study, we propose an online BCI-VR task: a car racing game (as shown in Fig. 1), which allows multiple users located at different sites to mentally play the car racing game in the same VE.

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