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ABSTRACT PROCEEDINGS

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Frequency, space and time tensor decomposition of motor imagery EEG in BCI applied to post-stroke neurorehabilitation*

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Abstract. We present a novel method of tensor decomposition of EEG for precise measurement and real-time tracking of narrowband brain oscillations (NBO) for brain-computer interfaces (BCI). To determine NBOs associated with specific limb movements, we used mirror-box therapy, in which users view mirror images of one limb moving to alter the NBO associated with the movement of the contralateral limb. Unlike purely imaginary motion, mirror-box imagery is specific and easy for users to control. Tensor decomposition is a machine-learning algorithm that separates the NBOs present in a multi-channel EEG and provides a spectral-spatial signature for precise measurement of each NBO. Using the signature of a NBO we can track its activity in real time by back-projecting the signature on a live multichannel EEG recording. This enables continuous monitoring of the synchronization and desynchronization of selected NBOs and the construction of an elegant BCI protocol. We applied this approach to rehabilitating post-stroke patients using the BCI control of a robotic splint and a virtual reality avatar hand.

Keywords: Tensor decomposition · Oscillations · Neurorehabilitation.

1 Introduction

A frequently used principle for creating motor imagery BCI protocols is the discrimination of event-related synchronization and desynchronization of sensorimotor rhythms, such as the well-known μ-rhythm. These rhythms have a narrowband, oscillatory character, and their dominant frequency has high inter-subject variability [1]. Therefore, monitoring the activity of sensorimotor rhythms requires abandoning the generally defined wide-frequency EEG bands, such as 8-12 Hz for α rhythm, and focusing on extracting subject-specific NBOs. Tensor decomposition based on PARAFAC or Tucker models represents an elegant

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solution for extracting and monitoring NBOs in BCI protocols. By introducing frequency and spatial constraints to improve the physiological plausibility of the EEG tensor decomposition, we demonstrated excellent performance of tensor decomposition on simulated, and real EEG data [2]. We validate and discuss the practicality of a system that combines tensor decomposition of EEG and mirror-box therapy in a BCI system to rehabilitate post-stroke patients.

2 Methods

We obtain EEG data for a training set in single subject over several mirror-box therapy sessions. Preprocessing involves cleaning the EEG signal of artifacts and decomposing it into oscillatory and fractal components. Working only with the oscillatory component allows us to suppress the effect of broadband cortical activity, which is an unwanted signal. This is followed by tensor decomposition of the oscillatory component, which extracts latent EEG elements or atoms, each of which has a specific spectral-spatial signature. Incorporating certain constraints on the tensor decomposition ensures that each atom represents a unique NBO [2]. In the mirror-box system, these atoms represent the sensorimotor NBOs associated with the movement observation and reflect the sensorimotor rhythms activated during mental imagery. The atoms derived from the training set are used to start the BCI protocol, and their signatures can be continuously adapted as the neurorehabilitation training continues. We built the given procedure into the BCI process of motor neurorehabilitation using a robotic splint control and avatar hand control tasks in virtual reality (VR).

3 Results

We used the mirror-box, tensor-decomposition BCI system for motor neurorehabilitation training of four post-stroke patients. Two patients controlled a robotic splint and two an avatar hand in the VR. One patient participated in both tasks. The training generally ranged from 10 to 12 days, but we looked at longitudinal effects by training for several months in one patient. Consistent clinical evaluation was part of the training protocol. In our contribution, we will report the performance, user acceptability, clinical results, and overall experience with the concept of tensor decomposition for BCI.

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