Hand Orthosis Controlled Using Brain-computer Interface

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Abstract

The purpose of this study was to construct a brain-computer-interface (BCI) based orthotic hand, including a prototype BCI system and a custom-made orthotic hand. The BCI can generate tri-state commands by processing a subject's mu wave while imaginary movement is performed, and the orthotic hand can be controlled to grasp, open and hold an object still. A BCI-based cursor control interface (visual feedback) with a simple classifier is designed to pre-train a naïve subject for performing imaginary movements. Then the classifier is adjusted to adapt to the subjects' EEG features for controlling the orthotic hand. The orthotic hand can be controlled under position and force modes, which are switched automatically by a logic controller depending on the commands and the current status of the orthotic hand. Three performance indices, namely, reaction time, information transfer rate and mean-squared error of force, were defined for evaluating the performance of the BCI-based orthosis under position and force control modes. The averaged success rates of three subjects were improved from 42% to 86% in 120 trials after pre-training. With the adaptive classifier, the averaged reaction time was reduced from 5 to 2 seconds under the position control mode, and the averaged information transfer rate was increased from 0.2 to 1.3 bit/trial. The mean-squared error of force was about 0.326 N while grasping an object under force control mode.

Keywords: Brain-computer interface (BCI), Orthotic hand, Orthosis, Biofeedback training

1. Introduction

Electroencephalography (EEG) is the electrical activity of the cerebral cortex recorded from the scalp. Clinically, EEG is sorted into delta, theta, alpha, beta and gamma waves according to the frequency range. Mu rhythm (8–14 Hz) is an alpha-range activity recorded from the primary sensorimotor area. When real or imaginary movements of the contralateral limbs are attempted, the power of mu rhythm is reduced. The difference of power before the attempt and about 1 to 2 seconds after the attempts can be used to quantify the suppression of mu rhythm or event-related desynchronization (ERD) [1]. Mu rhythm has been commonly used as a control source of the brain-computer interface (BCI) due to its being highly correlated with voluntary movements [2-4]. Generally, a BCI provides an artificial pathway to translate the brain waves into commands and can be used as control sources of assistive systems (prostheses or orthoses) for stroke patients or those with spinal cord injury [5].

BCI can be implemented by many approaches, and it has been utilized for many applications. For example, BCI-based word-spelling systems [6,7] have been developed for patients who have problems in communicating with others. In order to help patients with movement disorders to restore basic movements, some research groups have used BCI to control functional electrical stimulation (FES) [8], prostheses and orthoses. Guger et al. [9] developed a BCI-based hand-like (right hand) prosthesis; though the prosthesis was designed to do simple actions like grasp and open, it was the first BCI-controlled prosthesis. Pfurtscheller et al. [10] designed a BCI-based hand orthosis with very simple structure and demonstrated that a well-trained tetraplegic patient can control a BCI-based orthosis very well. Chatterjee et al. [11] constructed a mu wave-based BCI to control cursor movement. In their system, vibrotactile stimulators were placed on the left or right upper arm for sensory feedback. The intensity of stimulator vibration could be regulated to provide sensory feedback. They found the vibration feedback helped the subject to regulate contralateral imaginary tasks. Murguialday et al. [12] designed a BCI-controlled Otto Bock prosthetic hand, in which a tactor or vibrator was placed on the subject's forearm as tactile feedback too. The BCI-based Otto Bock hand could be controlled to grasp/open and regulate the grasping force through a logical algorithm.

Though mu rhythm is one of the commonly used BCI sources, its ERD is highly variable among subjects [13]. This variability has been a challenging problem that must be solved before BCI can be practically implemented. Recent studies have revealed that biofeedback techniques can be used to train the subjects of BCI for larger amount of ERD on mu rhythm or

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