Virtual Hand Rehabilitation with Force Guidance Adaptable to Mental States using Brain-Computer Interface

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***Abstract*— This paper presents a virtual hand dexterity training system where force guidance is activated autonomously in real time depending on the mental states of user, which are determined by electroencephalogram (EEG) signals acquired using brain-computer interface (BCI). In the context of handwriting, when EEG signals suggests a certain level of frustration, assistive forces are produced as an aid to completing the desired strokes. The study provides insights toward the development of intelligent rehabilitation system with automated guidance and natural user interface for self-paced practice.**

I. INTRODUCTION

In the process of rehabilitation, the performance of trainees is evaluated by therapists who provide guidance on the fly. To increase the availability and frequency of training, intelligent systems that can provide such a closed loop feedback automatically would facilitate self-paced learning, enabling practice to be conducted as often as desired with machine-produced live supervision. The paper attempts to realize this idea by using EEG signals to determine the states of mind, which is assumed to be affected by one's performance, and provide on-demand assistance accordingly.

II. METHODS

The proposed system was created by extending a virtual haptic handwriting training system developed previously for children with cerebral palsy [1]. Robotic haptic device was employed in the system to generate force feedback to assist users in the process of writing Chinese characters. Two kinds of force feedback, i.e., guiding and dragging, were provided respectively to move the deviated virtual pen tip back to the desired path, and to push it to the end of the stroke. In the present system, guiding and dragging forces were activated simultaneously according to user's mental states as determined by EEG signals. The 14-channel wireless EEG monitoring headset EMOTIV EPOC+ was used as the BCI to record brain waves through the scalp. The research edition of the EMOTIV software development kit was used to process the signals and determine the corresponding mental states, e.g. frustration, engagement and relaxation. In this study, the level of frustration F, in the range of 0 (no frustration) to 1 (very frustrated), was used to trigger the assistive forces based on the assumption that users would be frustrated if they were unable to write properly, e.g. complex characters, and force guidance was needed as an aid. The mechanism was designed such that: (i) when $F \leq 0.1$, no force was produced; (ii) when $F \geq 0.9$, assistive forces were produced; (iii) for $0.1 < F < 0.9$, if assistive force was not activated and F increased by 0.3 within a certain period of time, assistance was triggered; on the contrary, if assistive force was being provided and F decreased by 0.3, force guidance was disabled.

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III. RESULTS & DISCUSSION

The proposed system was implemented on a notebook computer with an Intel Core i5-6200U 2.3 GHz CPU and 8 GB RAM, running Microsoft Windows 10 64-bit Home Edition. The computer was connected to the 3D Systems Touch 3D Stylus haptic device via USB interface. Fig. 1 shows the prototype (left) and the control panel (left).

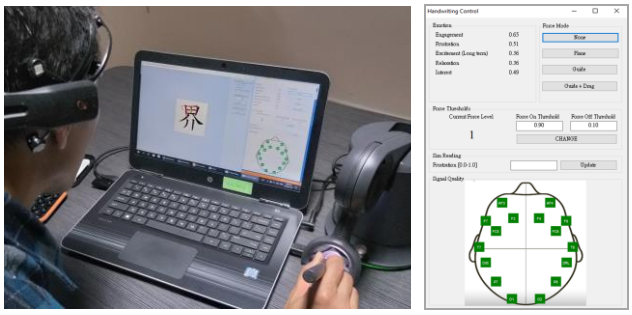

Figure 1. Hand dexterity training system with EEG-dirven haptic guidance.

Experimental results show that the prototype was able to produce assistive forces adaptively based on the triggering mechanism. The threshold settings will need to be optimized to increase the sensitivity. The system usability will also be investigated. Besides, the simple association assumed between user performance and frustration can be improved by including other mental states, e.g. fatigue [2], engagement or interest, to enhance the triggering mechanism. On the other hand, a custom classification model can be built to directly identify EEG signal patterns corresponding to different levels of training performance and provide assistance appropriately.

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