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Multi-mode Stroke Rehabilitation System Using Signal-Controlled Human Machine Interface

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A thesis submitted in partial fulfilment of the requirements for the degree of

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in
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Abstract

Stroke has become one of the most devastating health problems due to post-stroke disabilities. Rehabilitation is the necessary process for stroke survivors following discharging from the intensive care units. Of those stroke survivors, 82% of them cannot regain full arm functions, in turn, their daily lives are dramatically affected since they cannot perform daily activities such as eating, dressing, or taking showers independently. In recent years, technology-assisted rehabilitation is introduced using functional electrical stimulation, robotic devices, and virtual reality. Although technology-based systems have demonstrated advantages in early research, there are numerous aspects needed to be further investigated to ensure more stable physiological analysis of the affected upper limb and broader usage in the clinical field.

This thesis proposes a complete upper-limb rehabilitation system with multimodal motor function training using neuroelectric signals. First, motion intent recognition and emotion classification is analysed using electroencephalogram (EEG) signal. The EEG-based motion intent recognises the desired motion of stroke patients before the motion is executed. At the same time, emotions of the patients are monitored to ensure safety while the patients are doing exercises. Novel designed classifiers, including hybrid Support Vector Machine and hidden Markov Model and a Fuzzy-based Support Vector Machine, are demonstrated. The EEG-based classifiers are able to achieve 78% accuracy using novel machine learning algorithms, which improves 10-15% comparing with the classical methods.

Second, electromyography (EMG) is one of the most frequently used parameters since it reveals the electrical activity of a specific muscle that is related to the muscle force. In this thesis, EMG connectivity analysis using multivariable autoregression is proposed to analyse the inter-relationship between muscles. Using EMG connectivity analysis, the paretic arm is considered as the abnormal system, and the non-paretic arm is the reference side. The rehabilitation strategy is to control the abnormal system to generate identical EMG connectivity patterns as the reference side.

After integrating the layers controlled by physiological signals, a wearable exoskeleton is built as a rehabilitation device by mimicking human-like movements. The exoskeleton guides and supports rehabilitation movements based on the patients' physiological signals. After consolidating with physiotherapists and stroke patients, features such as wireless communication, low-power consumption, touch screen user interface, etc., are implemented to promotes the ease-of-use and expand the possible applications in the clinical field. At the moment, a clinical study that has recruited nine stroke patients is

conducted regarding outcome assessment and rehabilitation prediction. Followed by this study, the developed exoskeleton will be evaluated on stroke patients.

Author's declaration

I, *Kairui Guo* declare that this thesis, submitted in partial fulfilment of the requirements for the award of Doctor of Philosophy, in the *School of Biomedical Engineering*, *Faculty of Engineering and Information Technology* at the University of Technology Sydney, Australia, is wholly my own work unless otherwise referenced or acknowledged. In addition, I certify that all information sources and literature used are indicated in the thesis. This document has not been submitted for qualifications at any other academic institution. This research is supported by the Australian Government Research Training Program.

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List of Publications and Awards

Publications :

1. K. Guo, et al., 'EEG-based Emotion Classification Using Innovative Features and Combined SVM and HMM Classifier', IEEE EMBC 2017. (Chapter 2)
2. K. Guo, et al., 'EMG-Based Robot-Assisted Stroke Rehabilitation For Upper-limb Impairment,' ABEC 2018, Australia, 2018, p. 9. (Chapter 3)
3. K. Guo, et al., 'A Hybrid Fuzzy Cognitive Map / Support Vector Machine Approach for EEG-based Emotion Classification Using Compressed Sensing', International Journal of Fuzzy Systems, S.I.: Fuzzy System Big Data Mining, 2019. (Chapter 2)
4. K. Guo, et al., 'A Hybrid Physiological Approach of Emotional Reaction Detection Using Combined FCM and SVM Classifier', IEEE EMBC 2019. (Chapter 2)
5. K. Guo, et al., 'Puzzle-based Upper Limb Functional Electrical Stimulation Strategy Using EMG Connectivity Analysis', IEEE EMBC 2020. (Chapter 3)

Awards :

1. Lam Yuen Trust and ACETCA Medical Research Award at University of Technology Sydney in 2017
2. DST Group and UTS - Student Innovation Competition, Emerging Disruptive Technology Assessment Symposium 2017
3. UTS, FEIT HDR Collaboration Experience Award 2019
4. 2019 John Heine Memorial Foundation International PhD Prize
5. 2020 UTS Techcelerator, Most Feasible Prototype Award

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