UNIVERSITI TEKNOLOGI MARA

INTELLIGENT CONTROL TECHNIQUE OF FES-ASSISTED ELLIPTICAL STEPPING EXERCISE IN HEMIPLEGIC REHABILITATION

SAIFUL ZAIMY BIN YAHAYA

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CONFIRMATION BY PANEL OF EXAMINERS

I certify that a panel of examiners has met on 19th April 2018 to conduct the final examination of Saiful Zaimy Bin Yahaya on his **Doctor of Philosophy** thesis entitled "Intelligent Control Technique of FES-Assisted Elliptical Stepping Exercise in Hemiplegic Rehabilitation" in accordance with Universiti Teknologi MARA Act 1976 (Akta 173). The Panel of Examiners recommends that the student be awarded the relevant degree. The panel of Examiners was as follows:

Norsuzila Ya'acob, PhD
Associate Professor
Faculty of Electrical Engineering
Universiti Teknologi MARA
(Chairman)

Mohd Hezri Fazalul Rahiman, PhD
Associate Professor
Faculty of Electrical Engineering
Universiti Teknologi MARA
(Internal Examiner)

Muhammad Sharfi Najib, PhD
Associate Professor
Faculty of Electrical & Electronics Engineering,
Universiti Malaysia Pahang
(External Examiner)

Khaled Goher, PhD
Lecturer
School of Life & Health Sciences
Aston University, United Kingdom
(External Examiner)

PROF SR TS DR HJ ABDUL HADI HAJI NAWAWI
Dean
Institute of Graduates Studies
Universiti Teknologi MARA
Date : 1 November 2018

ABSTRACT

Rehabilitation exercise has been regarded as one of the promising methods to regain functions for people suffering from hemiplegic. In recent decades, rehabilitation exercise with the use of functional electrical stimulation (FES) has been the focus among researchers with a variety of exercise techniques involved. Rehabilitation exercise with the use of wheelchair accessed elliptical stepping ergometer has not much been explored especially on the practical adaptation of the users and control technique for FES. The studies in this research aimed to propose a new design of elliptical stepping ergometer and enhance the performance of FES-assisted elliptical stepping exercise through the design and implementation of intelligent control technique. The studies started with the design of the elliptical stepping ergometer that allowed for wheelchair access and incorporates between FES and voluntary movement in actuating the exercise movement. This involves the design concept, development of a model and a prototype. The complete system model of the FES-assisted elliptical stepping exercise was validated via an experimental work with the prototype. In the control technique design, early investigations was done on the performance of an FES-assisted elliptical stepping exercise controlled by proportional-integral-derivative (PID) controller. The control technique was further improved using the fuzzy logic controller (FLC). The FLC was proven to have better performance compared to PID. Further investigations was then carried out to improve the ability of FLC in enhancing the FES-assisted elliptical stepping exercise performance. A stimulation shifting technique was introduced to reduce the cadence error at the beginning of stimulation cycle due to delay in muscle response. Two techniques of stimulation shifting were developed that manipulated the stimulation pulse width and cadence error to enhance the FLC control action. A constant pattern of the FES signal was also taken into consideration in the control technique design. This control technique was realized by the implementation of the cycle-to-cycle control. In the implementation, two new FLC inputs were introduced to suit the movement nature of elliptical stepping. The inputs were the cadence error at the previous movement cycle maximum points and time per cycle error of the previous movement cycle. The FLC rules were also modified to generate suitable control action as a respond to the FLC inputs. Taking into consideration that an external assist via energy storage mechanism may improve the performance of FES-assisted elliptical stepping exercise, the installation of two types of energy storage mechanism which are linear extension spring and constant force spring were carried out. These techniques allowed the spring to store the excess force at the end of a movement cycle and release it as an assist force at the start of the next movement cycle. The FLC cycle-to-cycle control was maintained as the control technique. In the all mentioned control techniques, an optimization technique based on GA and PSO were used to optimize the parameters involved. Based on the analysis, all control techniques were significantly enhanced the performance of the FES-assisted elliptical stepping exercise. The best performance was shown by FLC stimulation shifting where it was recorded with 1.998 RPM of overall average cadence error. All in all, this indicated the potential use of FES-assisted elliptical stepping exercise with the designed control techniques as methods in hemiplegic rehabilitation.

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CHAPTER ONE
INTRODUCTION

1.1 Research Background

Hemiplegic is a half side body paralysis caused by neurological disorder. Stroke is a main factor that causes hemiplegic. Stroke is currently the third killer disease in Malaysia after heart disease and cancer. According to the National Stroke Association Malaysia (NASAM), there are an estimated 40,000 cases of stroke every year in Malaysia. Due to the increasing number of population and lack of awareness for healthy lifestyles, the number of cases are expected to increase year by year. Ischemic stroke incidence is estimated to increase 29.5% annually and hemorrhagic stroke by 18.7% [1]. There are many effects of stroke, but the most common is weakness or paralysis on one side of the body called hemiparesis or hemiplegia [2]. Hemiparesis refers to some inability to move while hemiplegia refers to a complete inability to move. This may affect the face, an arm, a leg or all three areas, and can range from mild weakness to total loss of movement [2]. This condition will therefore limit the activity that the patient can carry out which would affect the normal life of the patient.

Hemiplegic has potential to recover or at least returning certain level of functions. But without proper treatment, the effects of the patient at the chronic stage would become long-lasting. Thus, the rehabilitation process must start as soon as possible. At the time of starting the rehabilitation process, the subject would already have had chronic stroke (acute stroke – within 1 week of stroke, mild stroke – between 1 week to 1 month, and anything above one month is considered as chronic stroke). The rehabilitation process helps the patients into getting back to their normal life by achieving the best level of independence [3]. Instead of medication, physical exercise training known as rehabilitation exercise is one of the promising methods in the rehabilitation process. This involves passively or actively activating the muscle of the affected body part. Several studies have agreed that physical exercise training has the potential to encourage the function in regaining and preventing recurrent stroke [4-5]. On the other hand, another studies mentioned that the degradation of muscle mass is