

# Knee Joint Impedance Hybrid Modeling and Control of Functional Electrical Stimulation (FES)-Cycling for Paraplegic: Free Swinging trajectory

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**Abstract-** Functional electrical stimulation (FES) has been used to restore the function of paralyzed muscles due to spinal cord injury (SCI). FES induced movement control is a significantly challenging area due to complexity and non-linearity of musculoskeletal system. A crucial issue of FES is the control of motor function by the artificial activation of paralyzed muscles due to the various characteristics of the underlying physiological/biomechanical system. Muscle response characteristics are nonlinear and time-varying with fatigue issues. In this approach only the quadriceps muscle is stimulated to perform the trajectory motion. This paper presents the initial development of control strategies using FLC and GA in order to optimize the system by FES-cycling trajectory control via Analog Digital Converter, ADC.

**Keywords-** Functional electrical stimulation, fuzzy logic, genetic algorithm, paraplegic, ADC.

## I. INTRODUCTION

Nowadays, developments of control system due to paraplegic area nowadays are really improved and more beneficial by using functional electrical stimulation (FES). Since 1960s, FES has been used to correct foot drop, which is a common symptom in hemiplegia characterized by a lack of dorsiflexion during the swing phase of gait which results in short, shuffling strides in stroke patients [1,2]. The first application of FES was designed to restore lower limb function in patients who had experienced a stroke or a SCI [3]. FES is a promising method to restore mobility to individual paralyzed muscles due to spinal cord injury (SCI) [4,5,6]. SCI is defined as damage to the spinal cord that in turn causes the loss of function resulting in reducing mobility [7].

The application of FES as a therapeutic and rehabilitation modality has the potential to increase strength, voluntary movement, force production of the muscle, and functional skill abilities [8]. FES rehabilitation application also has a beneficial effect on the bones, muscles and cardiovascular system,

by reducing tension with good blood circulation [9-13]. Furthermore, FES system can be used to regulate the function of heart, breathing and coughing, to improve urine incontinence and mainly to improve the functions of human lower extremities such as standing, walking and the functions of upper extremity such as effectively grasp, manipulate and release of objects. In other things, when FES is applied to the muscles in patients with certain or varies frequencies and amplitudes of generated electrical stimulation, the stimulated muscles generate contraction

The development of control system also focuses on efficiency aspects of paraplegic cycling and underlines the advantages of an assisting motor in FES-cycling systems, both for the efficiency investigations and as a driving support [14]. Therefore, auxiliary motors can enhance FES-cycling performance, the overall power is increased, the loss of power due to muscle fatigue can be compensated and leg cycling motion can be maintained [15]. Application of cycling is abroad. Cycling is also a more efficient way of transportation, although the majority of FES cycling is done with stationary bikes. In FES cycling, the quadriceps, hamstrings and gluteal muscles are stimulated. Sometimes the calf muscles are also stimulated [16]. The developments of paraplegic knee and hip joint models and control strategy for mobile FES-cycling are the aims of this research. The developed knee and hip joint models should be capable of relating electrical stimulation and joint angle specifically for FES control development [17].

## II. THEORETICAL BACKGROUND

This project is concerned with the development of a paraplegic knee and hip joint model and control of electrically stimulated muscle for FES-cycling [18]. This research contributes to develop the Mobile FES-cycling systems with motor assist. The modelling of musculoskeletal of paraplegic's lower limb is significantly challenging due to the complexity of the system [17]. The first aim of this study is to develop a knee and hip joint model that capable to relate electrical parameters to dynamic joint torque as well as knee angle for FES application. Then, the second aim of this study is to develop

FES-induced cycling control. A crucial issue of FES is the control of motor function by artificial activation of paralyzed muscles.

Major problems that limit the success of current FES control systems are nonlinearity of the musculoskeletal system and rapid change of muscle properties due to fatigue. Fuzzy logic control (FLC) with ability to handle a complex nonlinear system without mathematical model is used [7] [17-19].

### III. METHODOLOGY

Based on the flowchart of figure 1, development of this research starts with data gathering from experimental test by using FES for electrical stimulation test, hence pendulum test for knee joint experimental data by using Goniometer [17-19]. Data collection from anthropometric data is the data parameter of lower limb characteristic.

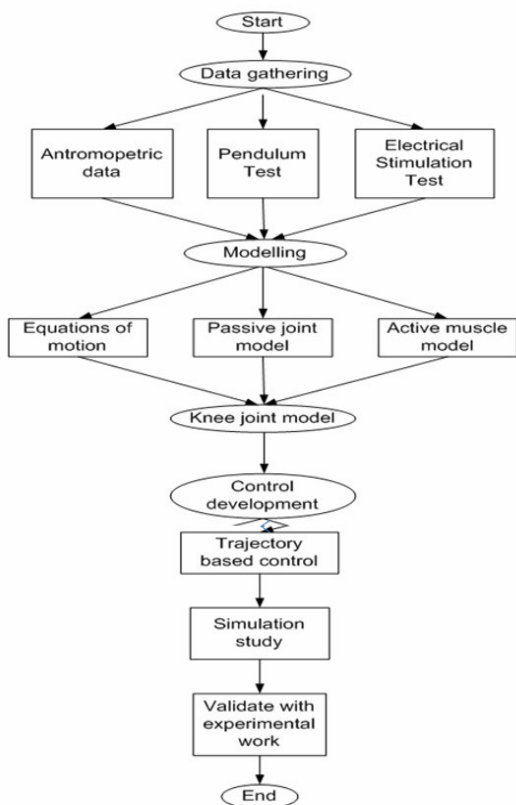


Figure 1: Flowchart of the system

In order to develop system with more efficient way and easy to handle for each procedure, every parameter will be developed by modelling each system by using Matlab Simulink. Combination of parameters by data gathering from previous literature study and data gathering process of this research is more on to develop equation of motion, passive joint model and active muscle model. The knee joint model is more on control development of trajectory based control in order to develop better knee joint model. Each control model will be developed in order to investigate the muscle fatigue characteristic using Matlab Simulink [17-19].

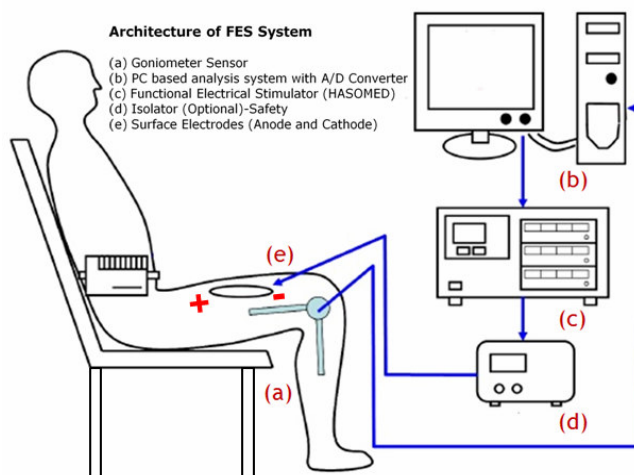


Figure 2: Architecture of FES System

Therefore, in order to develop control strategy of the system in this research, some architectures of FES system in figure 2 is reviewed. According to this architecture, it almost can be simplified as application of Analog to Digital conversion application by using Goniometer as the sensor and data will be selected and sampled by a software using Personal Computer, PC. Various data collection will be selected and sent to FES, (Hasomed GmbH) functional electrical stimulator will be generated automatically according to the developed model and system requirement [20].

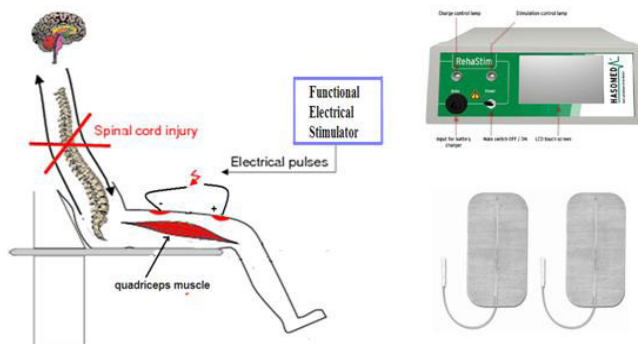


Figure 3: Application of Electrical Stimulator with surface electrodes

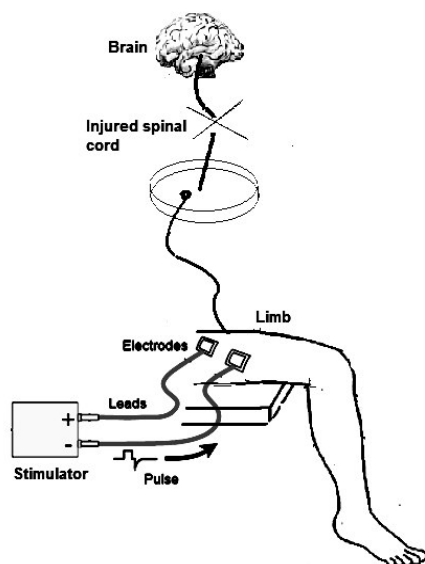


Figure 4: Basic configuration of FES

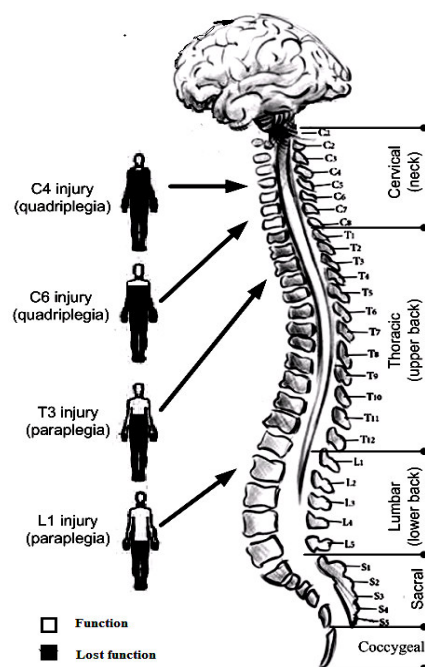


Figure 5: Effects of SCI depend on the type and level of the injury

Based on system requirement, basic configuration of FES system in figure 4 is more on basic fundamental of current or voltage flow between two surface electrodes through muscle. Stimulator will generate pulse in order to replace function of brain to control the lower limb muscle for current research [7]. Electrical stimulators generate electrical current. It can provide a constant voltage or constant current output. Stimulators which provide a constant output voltage can maintain a voltage that is desired irrespective of resistance changes, whereas stimulators with current output will make possible constant current pulse. Each signal can be single, double or multichannel. They need to have possibility to change parameters of electrical stimulation, such as stimulation pulses amplitude, frequency of stimulation pulses, duration of stimulation pulses and the stimulation pulse train. All these parameters have to be selected and adjusted by a therapist. A functional movement of a paralyzed extremity cannot be obtained by a single electric stimulus but a series of stimuli called a stimulation pulse train. It is triggered by a control signal [21].

Due to SCI problem that is illustrated in figure 5, pulse signals from brain cannot go through the human body system because of the signal have been blocked. Then every level of injury base on SCI problem which is divided into C6, C4, T3 and L1. In this research area, the focus is on lower limb paralysed injury of paraplegia and data will be collected during this research development study [7]. Based on the experiment from the FES architecture in figure 2, other supporting equipments are needed during this research which is to achieve the goal in this project. Some kind of measuring meter such as Digital Multimeter and oscilloscope will be used with signal generator to generate pulse in order to compare pulses with FES (Hasomed GmbH) shown in figure 6.

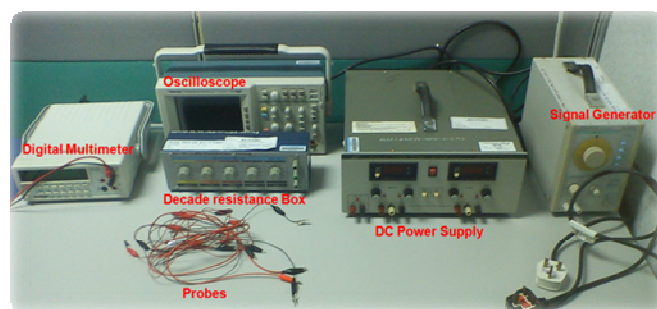


Figure 6: Equipment for experimental setup

#### IV. EXPERIMENTAL SETUP

This study is about is detection the angle due to free swinging motion of knee joint natural trajectory ranging from 0 to 90 degree. Basic experiment designed to detect the angle and displayed by 2 x 16 Hitachi LCD by using PIC18F4520 Microchip microcontroller as main controller. The system is consist on ADC, Analog to Digital Converter configuration . ADC commonly related to the potential sensor or transducer or equipment that converts the analog value to the digital data. In this preliminary setup, analog data produced from bend sensor which will be converted to digital value by the built in ADC of Microchip PIC18F4520[24].

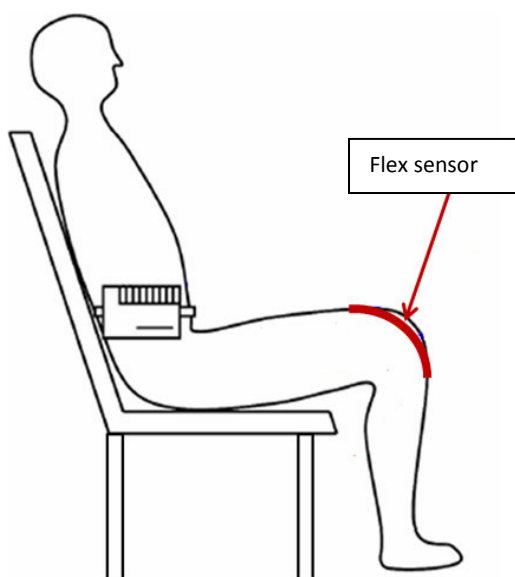


Figure 7: Placement of flex sensor on knee joints of normal person

TABLE I OVERALL SYSTEM DESCRIPTION

Knee joint impedance	
Parameter	Description
Controller	Microchip PIC18F4520
Board	Cytron SK40-C Circuit Board
Sensor	Flex Sensor: Bend Sensing Resistance
Software	MPLab IDE v8.43, Proteus7
Method/ Architecture	USART and ADC (PIC18 Library)

Description of the system summarized in Table 2. In order to measured the bending value, the bend sensor position at knee area by a secured knee guard based on Figure 1. Data displayed on the LCD represent the resistance and voltage measured corresponding to the bending degree counter checked by digital measurement.

#### V. PRELIMINARY RESULT

Data in Table 3constructed about resistance measured correspond to degree of bending by using digital multimeter at analog, AN pin of Microchip PIC18F4520.Data collected

based on angles of cycling trajectory in free swinging motion such as described in figure 8 based on human lower limb model.Data response based on the movement in scale  $10^0$  each until human leg at  $90^0$  at rest position. The lower limb model on f 8, angle data collected using a protractor with  $\pm 0.5\%$  tolerance human error. Major issues highlighted on human capability during gait and swing motion with simple measuring technique applied due to real paraplegic system and need to be upgraded with others character and parameter needs.In this case, majority of the rehabilitation researches involved the usage of exoskeleton type devices which, although can maintain correct movement form and can produce force inputs for therapy, but due to its large and complex built, it is not suitable for home-based rehabilitation device[25][26].

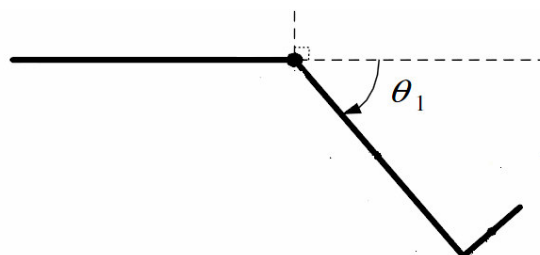


Figure 8: Lower limb model [6]

TABLE II MEASURED IMPEDANCE VALUE

Degree ( $^0$ )	Impedance (Kohm)
10	2.98
20	3.07
30	3.09
40	3.16
50	3.21
60	3.27
70	3.32
80	3.38
90	3.43

Data plotted in Figure 9 of relationship between degree and impedance value. Impedance of sensor based on bending processes either upward or downward position either increase the value of resistance or reduce the resistance. Thus, the degree of bending increase proportionally with the impedance

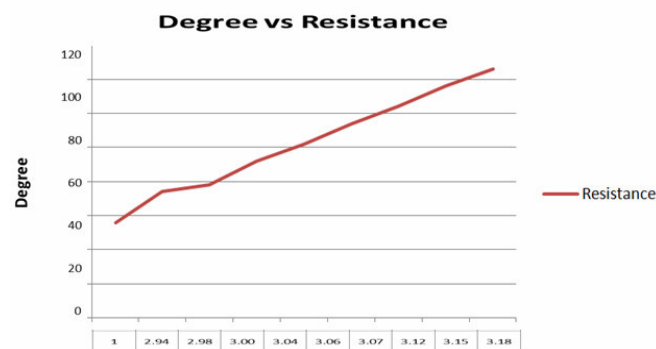


Figure 9: Relationship between degree and impedance value.



Voltage are proportional to the resistance  $V=IR$ . Voltage and resistance are in proportional and linear mode. Others tools that can used such as oscilloscope, digital probe and other analog or digital instruments that suitable for capturing data for analysis..

TABLE III: ADC DATA DESCRIPTION

<b>VDD</b>	5	Volt
<b>No of step</b>	1024	Steps
<b>Resolution</b>	10	Bits
<b>Step size</b>	5V/1024	0.004883
		4.88mV
<b>Dout (Decimal)</b>	$V_{\text{measured}} / \text{Step size}$	

#### Major Characteristics of the ADC

- Resolution: The higher resolution provides a smaller step size. **Step size =  $V_{\text{ref}}/\text{resolution}$**
- Conversion time: time takes to convert the analog input to a digital number.
- Vref
- Digital Data Output, **Dout =  $V_{\text{in}}/\text{step size}$**

By referring to Table 3, Voltage reference,  $V_{\text{DD}}$  in this research is 5V, due to simple and basic word, 5V in digital form equal to HIGH, or 1. Each data being summarized to step of size. Configuration of step size of PIC18F4520 ADC register is by 210,= 1024 steps in ADC. By calculation, step size is 4.88mv. Then values of is calculated by  $V_{\text{IN}}$  divide with step size, 4.88mv. Input Voltage,  $V_{\text{IN}}$  measured due to analog input voltage at AN pin. Values of  $D_{\text{OUT}}$ , Decimal, Binary and Hex calculated in Table 4 due to transform it into C program and divided into certain range depend on suitable value and condition that setup by user.

TABLE IV ADC CALCULATION BY VOLTAGE DUE TO DEGREE OF BENDING

Degree	Impedance (Kohm)	Voltage measured (v)	Calculation	
			Dout	Decimal
10	2.98	3.30	675.84	676
20	3.07	3.40	696.32	670
30	3.09	3.50	716.80	716
40	3.16	3.60	737.28	737
50	3.21	3.70	757.76	758
60	3.27	3.80	778.24	778
70	3.32	3.90	798.72	799
80	3.38	4.00	819.20	819
90	3.43	4.10	839.68	840

## VI. FUTURE CONSIDERATION

There are some limitation based on muscle fatigue problem and application for optimizing the performance of system by using FLC with GA Optimization [22]. Therefore, some adjustments based on control strategies in order to reduce fatigue, optimum work load with healthy life and minimum power consumption will be investigated. Another experiment setup will be proposed on relationship impedance value in another body area of human/person/patient in figure 10.

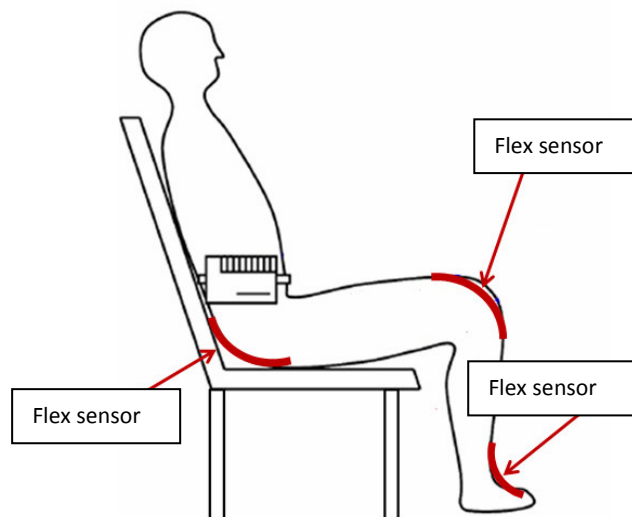


Figure 10: Proposed experiment

## VI. CONCLUSION

. This research is to help the paralysed people especially paraplegic individuals. FES is one of the most effective ways to improve gait in individuals after stroke or SCI. The investigation on the control strategy development of FES-assisted cycle with ability to control the movement and developed method on impedance with relationship joint of knee, hip and ankle.

## ACKNOWLEDGMENT

All this research work is fully funded by Fundamental Research Grant Scheme (FRGS), Ministry of Higher Education, Malaysia and supported by the Research Management and Innovation Centre, Universiti Tun Hussein Onn Malaysia (UTHM) under contract vot 0887.

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