"I hereby declare that I have read through this report entitle "Arm Rehabilitation Device Controller Based on Fuzzy Logic Techniques" and found out that it has comply the partial fulfillment for awarding the degree of Bachelor of Electrical Engineering (Control, Instrumentation and Automation)"

Signature :……

Supervisor's Name :……

Date :……

ARM REHABILITATION DEVICE CONTROLLER BASED ON FUZZY LOGIC TECHNIQUES

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A report submitted in partial fulfillment of the requirements for the degree of

Bachelor of Electrical Engineering (Control, Instrumentation and Automation)

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2015

I declare that this report entitle "*Arm Rehabilitation Device Controller based on Fuzzy Logic Techniques*" is the result of my own research except as cited in the references. The report has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature :……

Name :……

Date :……

To my beloved mother and father

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ABSTRACT

In this thesis, the arm rehabilitation device controller based on fuzzy logic techniques is presented. Patients who has post-stroke may lose control of their upper limb. If they are treated with functional rehabilitation training, the patients can rehabilitate their motion functions and working abilities. These rehabilitation devices are used to recover the movement of arm after stroke. Many controllers had been used for the rehabilitation device and one of them is ANFIS-PID controller where Adaptive Neuro-Fuzzy Inference System (ANFIS) technique is the combination of fuzzy logic and neural network system. The objectives of this project are to develop arm rehabilitation device based on fuzzy logic techniques for rehabilitation. This paper presents the development mathematical modeling of the arm rehabilitation device by using System Identification and to design ANFIS-PID controller. Several transfer function is evaluated in order to represent the best performances for the system. The derived model is validated via simulation and experimental for stability analysis. Whereas the developed ANFIS is purposely as an inverse model to the system and there is a proportional-integral-derivative (PID) controller as a feedback control. EMG model also is integrated to the control system where Artificial Neural Network (ANN) is used to model the EMG. Simulation is conducted using MATLAB to validate the system performance that is integrated with EMG model via simulation. Then the performance is compared between ANFIS-PID controller and PID alone controller. ANFIS–PID controller reduced more tracking error compared to PID controller and demonstrates better results when applied to control system via simulation.

ABSTRAK

Dalam kertas ini, alat kawalan rehabilitasi lengan berdasarkan teknik *fuzzy logic* dibentangkan. Pesakit awal strok akan menghadapi masalah pergerakan anggota badan bahagian atas kebiasaanya pada lengan, pergelangan tangan, dan bahu. Untungnya, kebanyakan pesakit boleh dipulihkan fungsi motif dan juga kebolehan pergerakan jika mereka dirawat dengan latihan rehabilitasi yang efektif. Alat robotic digunakan untuk memulihkan pergerakan lengan selepas strok. Banyak jenis kawalan yang telah digunakan untuk penggunaan alat rehabilitasi dan salah satunya ialah *ANFIS-PID Controller* dimana teknik *Adaptive Neuro-Fuzzy Inference System (ANFIS)* yang juga kombinasi dari pada system *fuzzy logic* dan *neural network.* Tujuan projek ini adalah untuk memajukan alat kawalan rehabilitasi lengan berdasarkan teknik *fuzzy logic*. Kertas kerja ini membentangkan model matematikal menggunakan Sistem Identifikasi untuk alat rehabilitasi lengan dan kemudian *ANFIS-PID Controller* direka bentukkan. Beberapa *transfer function* akan dinilai dan dianalisis untuk memberikan hasil respon yg terbaik untuk system ini. Model tersebut akan disahkan melalui simulasi dan experimentasi untuk analisis kestabilan. Manakala perkembangan ANFIS adalah bertujuan sebagai *inverse model* kepada sistem dan terdapat *PID controller* sebagai kawalan tindak balas. Model EMG juga diaplikasikan ke sistem kawalan dimana *Artificial Neural Network (ANN)* digunakan untuk memodelkan EMG. Simulasi dijalankan menggunakan MATLAB untuk mengesahkan respon sistem apabila EMG diaplikasikan melalui simulasi. Kemudian, respon tersebut akan dibandingkan antara *ANFIS-PID controller* dan *PID controller*. *ANFIS-PID controller* mengurangkan lebih banyak *tracking error* berbanding *PID controller* dan mendemonstrasikan keputusan yang bagus apabila diaplikasikan dalam sistem kawalan melalui simulasi.

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CHAPTER 1

INTRODUCTION

1.1 Background of study

Stroke is the third largest cause of death in Malaysia [1]. Ever year estimated about 40,000 people in Malaysia suffer from stroke and it is examined to be the single typical cause of severe disability. In 2010, American Heart Association identified the robot assisted therapy as a method of rehabilitation which can provide resistance or assistance of movement, accurate feedback, and also as a method to provide rehabilitation to the patient with less assistance from the therapist. Furthermore, it also mentions that "Current robots tend to exercise only the proximal arm, and then improve motor skills at the shoulder and elbow but not those of wrist and hand; consequently, robots that only train the shoulder and elbow are limited in their ability to improve completion of Activities of Daily Living (ADL)[2]". Besides, various control techniques have been proposed and researched to solve the motion control problems, but the neural network and fuzzy logic are most reported design that relies on control techniques[3]. Artificial neural network and fuzzy logic is used by the researchers to control many types of human movements such as walking, cycling, free swing legs, swimming and some others movement. To compare with conventional, these techniques are a bit different and have unique abilities in identifying the relationship of mathematical in a complex system and operating of nonlinear system [4]. Furthermore, for the fuzzy modeling method, the neuro-adaptive learning technique gives a procedure to get information about the data set and hence the fuzzy logic able to evaluate the membership function parameters that enable the associated fuzzy inference system to follow the

input and output data given [5]. ANFIS control algorithm is better performance due to its robustness in nonlinear systems [5]. ANFIS also generate intelligent self-learning by combining the fuzzy logic with the neural networks which led to many applications in the past time. Established on Sugeno type of inference system ANFIS has special architecture which able the use of hybrid learning algorithm [6]. This present paper purposes to develop an adaptive controller that gives a good performance compared to PID controller even when integrated with EMG model via simulation.

1.2 Motivation

i. To help stroke patients in activities they do in real life and decrease long term healthcare costs on stroke patient.

ii. The arm rehabilitation devices can achieve long term results compare to the therapist training.

iii. Modelling a plant along with a controller to gain a better performance in controller design.

iv. Overcome the limitation from previously control techniques.

1.3 Problem Statement

Nowadays, there are many researchers have carried out a lot of solution and design to improve the arm rehabilitation devices. However, most of the researchers only focused on kinematics models of rehabilitation devices. The arm rehabilitation devices must be more functional for example, in case of the controller used must be effective and robust to the desired system. Therefore, this project will be start by developing a mathematical modeling of the arm rehabilitation devices and designing ANFIS-PID controller. An accurate system modeling is crucially important to represent the system well. Inaccurate model will jeopardize the overall control system later on. Furthermore, the performance of the controller is validate by integrate EMG model via simulation. The proposed control system needs to become adaptive to the nonlinearity of the EMG model. MATLAB software will be used to analyze this project where the proposed controller design which is ANFIS-PID controller is compared with PID controller and validate via simulation in order to improves the functionality of the controller.

1.4 Objectives

The objectives of this project are

i. To develop mathematical modeling of the arm rehabilitation device using System Identification technique.

ii. To design ANFIS-PID controller for the system in term of position tracking using MATLAB/Simulink software.

iii. To validate the system performance that is integrated with EMG model via simulation.

1.5 Scope of project

In this study, the rehabilitation device only focuses on one arm/ upper limb muscle of the right hand while the wrist joint is neglected. To ensure project objectives are achieved, some scopes are identified which is;

i. Using System Identification to find transfer function from experimental data and evaluate the stability analysis.

ii. Modeling EMG position relationship using ANN.

iii. Fuzzy logic technique will be developed to design the ANFIS-PID controller for position tracking.

iv. The chosen software is MATLAB which is used in designing the controller and applied to the control system via simulation.

v. Integrate EMG model as references to the control system.

CHAPTER 2

LITERATURE REVIEW

2.1 Overview

Literature review is a process reviewing written and published knowledge that related on this project and which is included in research through the journal, book, articles, magazines, website, conference proceeding, thesis and other sources that can be applied. The reviews are includes the arm rehabilitation devices controller and the fuzzy logic techniques which is ANFIS-PID controller that applied ANFIS Inverse model and PID controller at the feedback of the control system. This chapter also discussed about the devices that has been used which are related to this rehabilitation device controller.

2.2 Arm Rehabilitation Devices

Robotic exercises devices are extensively used in rehabilitation training for the improvement of the patient's upper-limb [7]. To automate therapy for the arm, wrist and hand following stroke, the rehabilitation robotic devices and system are being developed. As shown in Figure 2.1 the upper limb has several DOFs and it is very difficult to doing the rehabilitation as it really is [7]. The parameters that needed to control from Figure 2.1 are angle position.

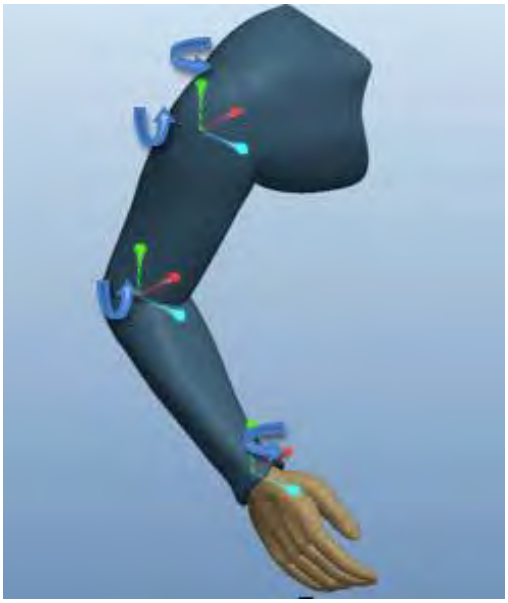

Figure 2.1: Human arm structure

In recent years, a number of devices have been developed expressly for arm rehabilitation. Robotic devices designed for arm rehabilitation of stroke patients are such as the MIT-Manus (Massachusetts Institute of Technology Manus) [8] (Figure 2.2.a) and Assisted Rehabilitation and Measurement (ARM) Guide [8] (Figure 2.2.b).

Figure 2.2: Robotic Devices for Arm Rehabilitation

2.3 Previous Research

2.3.1 Comparison of Existing Model

Much works have been done in the area of robotic rehabilitation for the upper limbs. Many previous devices have also proved the interest of robot-assisted therapy in helping dependent people with disabilities. There are many type of controller that can be chooses to design in creating arm rehabilitation devices. Robot assisted therapy systems need three elements which are algorithms, robot hardware and computer system [9]. Moreover, the design of the control system is a one of the main difficulties especially when intending to realize predefined complex movement and recovering at the same time motion and force human capabilities/ force [10].

In this paper, [7] fuzzy logic incorporating with the hybrid controller was developed to restriction the motion in the desired direction and to maintain a constant force along the moving direction. The planned movements of circular or linear trajectories were considered. The controller was stable in the implementation range of forces and movements. To quantitatively

assess the progress of rehabilitation, offline analyses of data were used. The upper limb of subjects can be conducted by the robot in linear and circular movements under predefined external force levels and a desired force is applied along the tangential direction of the movements [11].

On the other hand, [12] in a new control architecture which is development of high-level controller design is presented that work in combination with the low-level controllers where it can dynamically determine the task updates based on patient's performance. The safety related events is monitored in an automated manner and generate an accommodating plan of action such as, MIT Manus uses impedance controller while MIME uses PID controller for movement assistance. However, each low-controller and high-controller may require different types of inputs and outputs so they cannot communicate directly [12]

Meanwhile, for the fuzzy logic controller used in stability analysis where the main advantages of this technique seem to be the possibility of applying "rule of the thumb" experience and it does not need a model of the process. Whereas, the disadvantages of this method seem to be lack of appropriate tools for analysis of the controller performance such as stability, optimality, etc [13].

Fuzzy logic in control system is examined as an alternate for conventional control theory where definite mathematical modeling is impossible or harder in the control of nonlinear system. it also requires less multiplex mathematical operations compared to classical controllers such as PID controller [14]. Between the proportional control and fuzzy control, it shown that the fuzzy control particularly decrease the overshoot percentage and essentially eliminated limit cycling. Applying fuzzy algorithm in a controller gives a faster and more accurate response compared to the other industrial controller [15].

On the other hand, many control application is extensively used such as PID controller because of its potency and implicitly. PID controller has been used a long time in the field of engineering and commonly the three controller gain parameter is fixed. But the PID controller limitation is it is terrible in dealing with system uncertainty which is parameter variations and external disturbance [15].

Based on paper [4], the composed method is used which is the evolved ANFIS works as an inverse model to the system and PID controller at the feedback of the system. The ANFIS-PID is designated to control knee joint during sit to stand movement to quadriceps muscles through electrical stimuli. Referred to the simulation results, the ANFIS-PID successes improving sit to stand execution compared to the PID controllers. The results of this study give better performance compared to the other studies which use Fuzzy Logic or Neural Network intelligent techniques concerning to minimizing errors during tracking desired motion. In conclusion of this study, ANFIS-PID controller indicates a slightly better performance rather than the ANFIS alone controller and PID controller.

2.3.2 Adaptive Neuro –Fuzzy Inference System (ANFIS)

From the gain research, ANFIS is the executions of fuzzy inference system (FIS) to adaptive networks for generate fuzzy rules with ideal membership function to get the required inputs and outputs. Fuzzy theory is used where fuzzy-if-then rules and fuzzy reasoning produce bases conduct mapping from a given input knowledge to desired output [16]. A feed-forward multi layer Artificial Neural Network (ANN) is an adaptive network with relatively or fully, adaptive nodes in which parameter of adaptive nodes predicted the output and the learning rules described the adjustment of parameters due to error term. Learning type in adaptive ANFIS is hybrid learning and the configuration of ANFIS is shown in Figure 2.3 below [16].

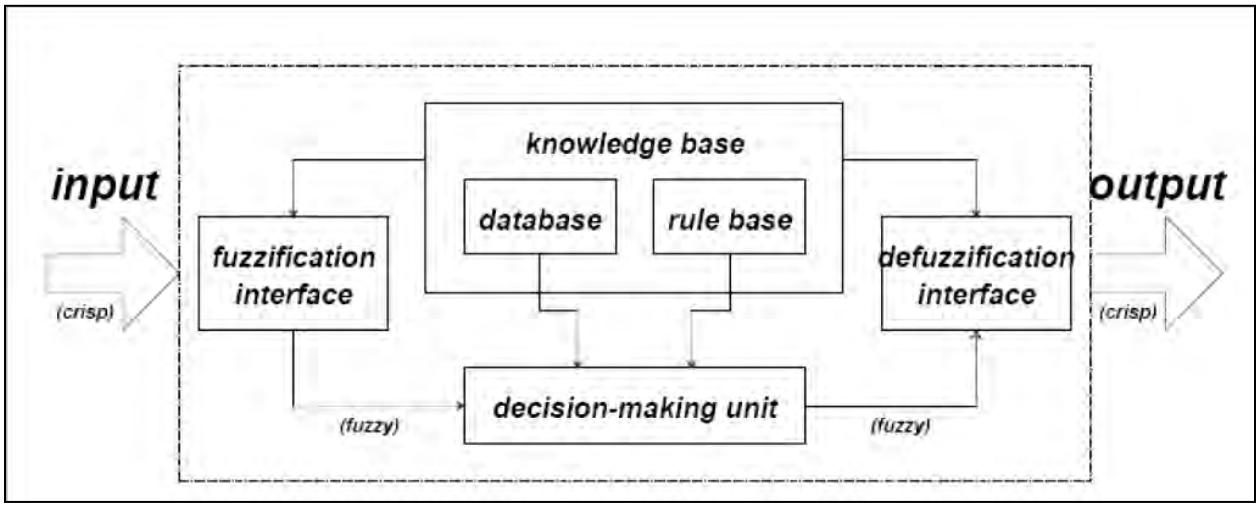

Figure 2.3: Configuration of ANFIS