MODELING AND CONTROLLER DESIGN OF A SINGLE-LINKED INVERTED PENDULUM USING OPTIMIZED FUZZY LOGIC CONTROLLER APPROACH

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DEDICATION

This thesis is dedicated to my father and mother who have been very supportive in ensuring that I come this far and continually encouraging me to aspire for more. It is also dedicated to all my siblings who were always there to encourage me when the going got tough and supported me through-out.

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ABSTRACT

Inverted pendulum (IP) is an underactuated systems, since the input of the system is the force applied to the cart and the outputs are the cart position and pendulum angle (SIMO) system, which makes this system is highly nonlinear and unstable. Inverted pendulum considered as the one the most famous classical systems in the field of control and mechatronics. This project focuses on the design of a fuzzy controller to stabilize an inverted pendulum in a vertical position. A continuous correction mechanism is required to move the cart in a certain way in order to balance the pendulum to prevent it from falling down. This project started by a derivation of the mathematical model of the single linked inverted pendulum system by using Euler-Lagrange method. After that, a fuzzy logic controller (FLC) based Sugeno inference system was designed and genetic algorithm was used to tune the parameters of the controller using MATLAB software. Both controllers were tested using real time inverted pendulum. Experimental results showed that optimized FLC was much better than Sugeno FLC in terms of settling time, overshoot and steady state error.

ABSTRAK

Pendulum terbalik (IP) adalah sistem yang tidak aktif, kerana input sistem adalah daya yang diterapkan pada gerobak dan outputnya adalah posisi kereta dan sistem pendulum sudut (SIMO), yang menjadikan sistem ini sangat tidak linier dan tidak stabil. Pendulum terbalik dianggap sebagai sistem klasik yang paling terkenal dalam bidang kawalan dan mekatronik. Projek ini memfokuskan pada reka bentuk pengawal kabur untuk menstabilkan bandul terbalik pada kedudukan menegak. Mekanisme pembetulan berterusan diperlukan untuk menggerakkan gerobak dengan cara tertentu untuk mengimbangkan bandul agar tidak jatuh ke bawah. Projek ini dimulakan dengan penurunan model matematik sistem pendulum terbalik tunggal yang dihubungkan dengan kaedah Euler-Lagrange. Setelah itu, sistem inferensi Sugeno berdasarkan pengawal logik kabur (FLC) dirancang dan algoritma genetik digunakan untuk menyesuaikan parameter pengawal menggunakan perisian MATLAB. Kedua-dua pengawal diuji menggunakan bandul terbalik masa nyata. Hasil eksperimen menunjukkan bahawa FLC yang dioptimumkan jauh lebih baik daripada Sugeno FLC dari segi masa penyelesaian, overhoot dan kesalahan keadaan tetap.

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LIST OF ABBREVIATIONS

ANFIS	-	Adaptive Neuro Fuzzy Inference System
ANN	-	Artificial Neural Network
BP	-	Back Propagation
DoF	-	Degree of Freedom
FIS	-	Fuzzy Inference System
FLC	-	Fuzzy Logic Controller
GA	-	Genetic Algorithm
IAE	-	Integral Absolute Error
IP	-	Inverted Pendulum
LQR	-	Linear Quadratic Regulator
MF	-	Membership Function
MIMO	-	Multiple Input Multiple Output
PNFC	-	The Proportional Neuro Fuzzy Controller
PSO	-	Particle Swarm Optimization
PID	-	Proportional-Integral-Derivative
SIMO	-	Single Input Multiple Output
SISO	-	Single Input Single Output
SMC	-	Sliding Mode Controller
T-S FLC	-	Takagi Sugeno Fuzzy Logic Controller

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CHAPTER 1

INTRODUCTION

1.1 Background Study

Inverted pendulum (IP) considered as the one the most famous classical systems in the field of control and mechatronics. The inverted pendulum on cart comprises of a cart, whereas this cart is usually attached to the motor, which is enabling it to move in the horizontal plan only (forward and backward directions) and a pendulum rod, which is connected to a pivot point attached to the bottom of the cart and can move freely in both vertical and horizontal directions [1]. Inverted pendulum is an underactuated systems, which means the number of system actuators is less than the number of dof of the system, since the input of the system is the force applied to the cart and the outputs are the cart position and pendulum angle (SIMO) system. This makes this system is highly nonlinear and unstable [2]. Thus, the inverted pendulum is a typical experimental to test the performance of many controllers.

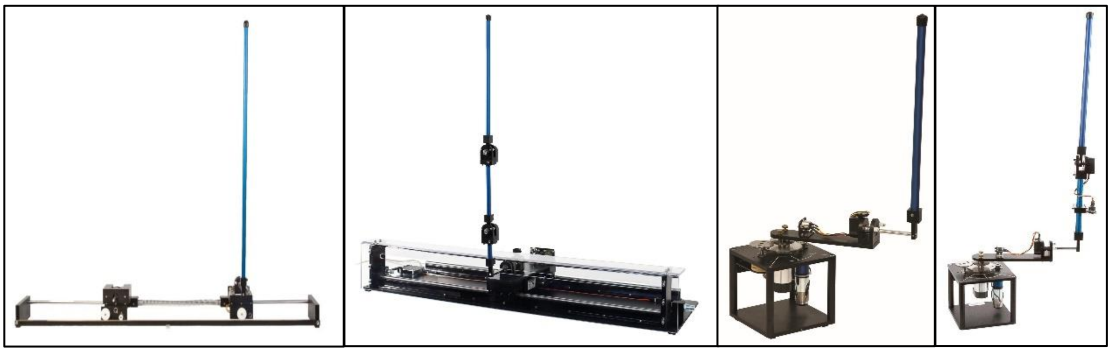
There are three control problems related to the inverted pendulum system [3], as follows:

1. Swing up problem: its aim is to swing up the pendulum from its downward position to the vertical position.
2. Stabilization problem: it is considered as linear control problem, since the linearized model is required before designing the controller, the main objective is to stabilize the pendulum on a vertical upright position.

3. Tracking problem: its objective to keep the cart follows the desired trajectory effectively.

The controlling methods of the system has wide range applications vary from simple to most complicated in our real-time world, such as rockets propeller, tank missile launcher, self-balancing robot, biped walking, satellites, aerospace vehicle systems [4].

There are four main configurations of inverted pendulum systems with different characteristics and degrees of freedom as shown in Figure 1.1, which are Single-Linked Inverted Pendulum (SIP) in Figure 1.a, Double Inverted Pendulum (DIP) in Figure 1.b, Rotary Inverted Pendulum (RIP) as in Figure 1.c, and Rotary Double Inverted Pendulum (RDIP) in Figure 1.d.



(a) (b) (c) (d)

Figure 1.1 Types of Inverted Pendulum

In order to control inverted pendulum system many controllers have been designed to achieve the desired performance. These controllers can be categorized as linear controllers which include PID and optimal controllers (LQR, Pole Placement), nonlinear controllers like sliding mode and backstepping controllers, intelligent controllers, such as fuzzy controller and adaptive neuro fuzzy controllers, and hybrid controllers, which are combination of different controllers and optimization techniques [5].

1.2 Problem Statement

Inverted pendulum is highly non-linear and unstable system. Also, considered as underactuated system. Normally, the inverted pendulum is hanging downwards when no force is applied, and the cart is not moving. However, the pendulum is required to remain in the upright position by applying a continuous correction mechanism to move the cart in a certain way in order to balance the pendulum and prevent it from falling down.

1.3 Objectives

The project objectives are as follows:

1. To design fuzzy controller and optimized fuzzy controller with genetic algorithm.

2. To simulate and test the performance of the system and the designed controllers using simulation tool.

3. To verify the designed controller's performance using laboratory-based pendulum setup.

1.4 Scope of The Project

The followings describe the scope of the project:

- The nonlinear model will be used to describe system.

- The controllers are to be designed based on Fuzzy Logic Controller FLC and FLC based Genetic Algorithm GA to control both (cart position and pendulum angle).

- MATLAB software will be used to implement the controllers to test their performance.

- Validate the result by using the Inverted Pendulum system experimental hardware in Control Laboratory.

1.5 Organization of this Report

The subsequent chapters are organized as follows; Chapter 2 reviews relevant literature in the field of IP systems as well as some fuzzy and other controllers that have been used. Chapter 3 then discusses modelling of the IP system and the methodology used in the design of fuzzy controller. This is followed by Chapter 4 which highlights the simulation and experimental results. Chapter 5, which includes the conclusion and future work.

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