MODELING AND CONTROLLER DESIGN OF AN INVERTED PENDULUM SYSTEM USING AI APPROACH

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To my beloved Mother and Father

Any number of words cannot sufficiently express the love and encouragement I received from them

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ABSTRACT

This project presents the simulation study of few different control approaches that consist of modern controller and intelligent controller for an inverted pendulum system. Inverted pendulum is a nonlinear and unstable dynamic system, which continually moves toward an uncontrolled state. It consists of a cart, driven by a force that can move along a horizontal track, and a pendulum attached to the cart which can rotate freely in the vertical plane parallel to the track. The control problem is to drive the pendulum to its upright position and remains it there as well as maintaining the position of the cart. It involves the derivation of the mathematical modeling that includes the linearization of the model in order to be used with the linear controller. The work follows with designing linear quadric regulator (LQR) as modern controller; fuzzy logic and adaptive neural network fuzzy for the intelligent controller. The simulation of controllers has been done in MATLAB, and their performance is analyzed and compared which is based on common criteria's of the step response. Overall, LQR controller has the fastest response, whereas adaptive neural network fuzzy controller gives more flexibility in control action

ABSTRAK

Projek ini memaparkan kajian yang dijalankan melalui kaedah simulasi terhadap beberapa kaedah pendekatan kawalan yang mengandungi kawalan moden dan kawalan kepintaran untuk sistem ayunan bandul terbalik. Ayunan bandul terbalik merupakan sistem dinamik yang tidak linear dan tidak stabil, selalunya akan menyumbang kepada keadaan yang tidak terkawal. Ianya mengandungi pengangkut, dipandu oleh daya yang boleh bergerak sepanjang landasan melintang, dan bandul yang dipasang pada pengangkut yang berupaya untuk berputar di dalam satah menegak yang selari dengan landasan. Projek ini dihasilkan bagi memastikan ayunan bandul berada di dalam posisi yang menegak dan mengekalkan keadaan tersebut, dalam masa yang sama mengekalkan posisi pengangkut tersebut. Ia melibatkan terbitan model matematik yang akan digunapakai di dalam proses penglinearan model bagi menghasilkan pengawal linear. Projek ini disusuli dengan merekacipta pengawal moden *"linear quadric regulator (LQR)"* dan pengawal pintar *"fuzzy logic"* dan *"adaptive neural network fuzzy"*. Simulasi terhadap pengawal-pengawal telah diuji dengan menggunakan *"MATLAB"*, dan pelaksanaannya dianalisis dan dibandingkan. Secara keseluruhannya, pengawal *"LQR"* mempunyai respon yang paling pantas, manakala pengawal *"adaptive neural network fuzzy"* memberikan tindakan kawalan yang lebih fleksibel.

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b	-	Friction of cart
l	-	Length to pendulum centre of mass
x	-	Cart position coordinate
$\ddot{x}$	-	cart acceleration
θ	-	Pendulum angle from the vertical
$\ddot{\theta}$	-	Pendulum angular acceleration
r(s)	-	Reference signal
e(s)	-	Error signal
u(s)	-	Plant input
x	-	State vector
u	-	Input vector
y	-	Output vector
T_s	-	Settling time
T_r	-	Rising time
e_{ss}	-	Steady state error
NS	-	Negative small
NM	-	Negative medium
NL	-	Negative large
ZE	-	Zero
PS	-	Positive small
PM	-	Positive medium
PL	-	Positive Large

LQR	-	Linear Quadratic Regulator
FLC	-	Fuzzy Logic Controller
ANFIS		Adaptive Neural Fuzzy Inference System
GUI		Graphic User Interface
AI	-	Artificial Intelligence
M	-	Mass of cart
m	-	Mass of pendulum
CV	-	Control variable
E	-	Error
SP	-	Set point
PV	-	Process variable
R	-	Step input to the cart
A	-	State matrix
B	-	Input matrix
C	-	Output matrix
D	-	Direct transmission matrix
%OS	-	Percent overshoot
I	-	Inertia of the pendulum
F	-	Force applied to cart

CHAPTER 1

INTRODUCTION

1.1 General Introduction

An early study of the inverted pendulum system was motivated by the need to design controllers to balance rockets during vertical take-off. At the instance of time during launch, the rocket is extremely unstable. Similar to the rocket at launch, the inverted pendulum requires a continuous correction mechanism to stay upright, since the system is unstable at open loop configuration. This problem can be compared to the rocket during launch. Here, rocket boosters have fired in a controlled manner, to maintain the rocket upright.

The inverted pendulum offers a particularly compelling example for control engineers to verify a modern control theory. This can be explained by the facts that inverted pendulum is marginally stable, in control sense, has distinctive time variant mathematical model.

Inverted Pendulum is a remarkably convenient model for the attitude control of a space booster rocket and a satellite, an automatic aircraft landing system, aircraft stabilization in the turbulent air-flow, stabilization of a cabin in a ship etc. To solve such a problem with non-linear time variant system, there are alternatives such as real time computer simulation of these equations or linearization [1].

1.2 Problem Statement

The inverted pendulum represents a challenging control problem, which continually moves toward an uncontrolled state and must be actively balanced in order to remain upright.

The inverted Pendulum is a highly nonlinear, and open loop unstable system, in order to keep the system stable, force must be properly applied. To achieve a stable system, control theory is required. The principles and theories of an inverted pendulum must be understood clearly to obtain the right and more accurately controlled inverted pendulum model. Standard linear techniques cannot model the nonlinear dynamics of the system. When the system is simulated the pendulum falls over quickly.

Common control approaches such as Proportional-Integral-Derivative (PID) control and Linear Quadratic control (LQ) require a good knowledge of the system and accurate tuning in order to obtain desired performances. However, it is often impossible to specify an accurate mathematical model of the process, or the description with differential equations is extremely complex [2].

In order to obtain control surface, the inverted pendulum dynamics should be locally linearized. Moreover, application of these control techniques to a two or three stage inverted pendulum may result in a highly critical design of control parameters and difficult stabilization. However, using artificial intelligence controllers such as artificial neural network and fuzzy logic controllers, the controller can be design without require the model to be linearized. The nonlinear model can be simulated directly using the MATLAB application to see result [1].

1.3 Objective of Project

The main objective of this project is to develop software for computer control to model the inverted pendulum system. This process will begin with the derivation of a mathematical model for the inverted pendulum system. Mathematical modeling involves process to describe dynamics of system in a set of differential equations. The process will be followed by designing several controllers, which are capable of driving the pendulum to its upright position as well as maintaining the position of the cart. This project uses three methods in designing a controller, which consists of state-space for modern controller, fuzzy logic and adaptive neural network fuzzy for intelligent controller.

The second objective is to develop simulation of the controllers by using MATLAB SIMULINK. The purpose of simulation is to view results of controllers for stabilizing the inverted pendulum system.

The third objective is to perform comparison between controllers for the inverted pendulum system. The performance of modern and intelligent controllers will be compared to identify the most suitable controller design that satisfies all design requirements. The most common characteristics to be compared are steady state error, percentage of overshoot and the settling time in order to identify how good the response of the controller is.

1.4 Scope of the Project

The purpose of this project can be divided into four main parts; the first part is to derive the mathematical dynamic model that represents the inverted pendulum system. This includes the nonlinear model of the system as well as the linear model of the system in transfer function and state-space form.

After testing the performance of the inverted pendulum system, the second part involves the design of a conventional controller that is linear quadric regulator (LQR) controller as a mean of comparison. The design of intelligent controllers consists of fuzzy logic controller (FLC) and adaptive neural fuzzy controller (ANFIS). All controllers will be designed to control angle of the pendulum and the position of the cart.

The third part will be focused on implementation of controllers in simulation by using MATLAB to verify the effectiveness of the designed controllers.

The final part will be focused on detail analysis and justification of suitable controller for the system by performing a comparison base on the common criteria's of the step response to identify the best controller

1.5 Thesis Outline

The thesis consists of seven chapters. It begins with the introductory chapter. This chapter gives the brief description of the problem for inverted pendulum system, objectives of the project and scope of the project.

Chapter two discusses the literature review and related works from existing controller approaches to stabilize the inverted pendulum system.

Chapter three presents the research framework of this study. It will describe each phase of the research, beginning from deriving the mathematical model of the inverted pendulum, followed by design and simulation of controllers in order to have a detailed analysis for identifying the best approach for stabilizing the system.

Chapter four contains the overview of the inverted pendulum system with nonlinear factor, followed by comprehensive description for deriving the mathematical model for the dynamic of the system in differential form, transfer function form, and state space form.

Chapter five includes a discussion of the control theory and topologies that could be used to drive the pendulum to its upright position as well as maintaining the position of the cart. Three approaches will be described which are state-space controller, and two different methods of intelligent controller. This section as well discusses the procedure or steps to the realization of the entire controllers in the inverted pendulum system.

Chapter six will present the entire results from applied controllers. In this stage, analysis and comparison on the controllers' performance based on controlling angle of the pendulum and position of the cart will be presented. It will be based on the common criteria's of the step response such as a percentage of overshoot, rise time, settling time, and the steady state error.

Final chapter will give the conclusion of this thesis. All the problems occurred during this project will be emphasized; several recommendations and suggestions will be proposed to improve this project.

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