CONTROL OF INVERTED PENDULUM SYSTEM

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FAKULTI KEJURUTERAAN ELEKTRONIK DAN KEJURUTERAAN KOMPUTER

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To education, professionalism and all things that matter.

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ABSTRACT

An inverted pendulum is a device which has its mass freely oscillating above its pivot point. The implementation often involves a horizontal moving cart with the pivot point mounted on it. This innovation may also be called a cart and pole. Whereas a normal pendulum is stable when hanging downwards, an inverted pendulum is inherently unstable, and must be actively balanced in order to remain upright. This is done either by applying a torque at the pivot point or by moving the pivot point horizontally as part of a feedback system. Due to its structure simplicities, inverted pendulum is also frequently used as a standard to validate the performance and effectiveness of control methods. Therefore, this project aims to control the stability of this mass and its pole by supplying control input to the cart with appropriate control strategy. A mathematical model of this mechanism is to be developed in order to have a deeper understanding on the characteristics. Among the controller that will be experimented with this pendulum are Fuzzy Logic Controller and Sliding Mode Controller. The efficiency of these controllers will be simulated using the MATLAB Software and afterwards differentiated.

ABSTRAK

Bandul terbalik ialah sebuah alat yang mempunyai sebuah jisim berayun bebas di atas titik paksinya. Alat ini melibatkan sebuah kereta bergerak secara melintang bersama titik paksi tersebut dipasang di atasnya. Inivasi ini juga bleh digelar sebuah kereta dan tiangnya. Berbeza dengan bandul normal yang stabil digantung kebawah, sebuah bandul terbalik sememangnya tidak stabil dan harus aktif diimbangi supaya sentiasa ke atas. Ini dapat dilkukan samada dengan memberi kilas pada titik paksi atau menggerakkan titik paksi tersebut didalam suatu sistem suap balik. Disebabkan strukturnya yang mudah, bandul terbalik juga sering digunakan sebagai standard untuk mengesahkan prestasi dan keberkesanan kaedah kawalan. Oleh itu, matlamat projek ini ialah untuk mengawal kestabilan jisim dan tiangnya dengan memberikan input strategi kawalan yang sesuai kepada kereta bandul. Sebuah model matematik berkenaan mekanisma ini akan dibangunkan untuk mendapat pemahaman yang lebih baik ke atas cirri-cirinya. Antara pengawal yang akan dikaji adalah Pengawal Logik Kabur dan Pengawal Mod Meluncur. Kecekapan pengawal-pengawal ini akan disimulasikan di dalam perisian Matlab dan kemudiannya dibandingkan.

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CHAPTER I

INTRODUCTION

1.1 Overview

The inverted pendulum is a classic problem in dynamics and control theory and widely used as benchmark for testing newly developed control strategies. Variations on this problem include multiple links, allowing the motion of the cart to be commanded while maintaining the pendulum, and balancing the cart-pendulum system.

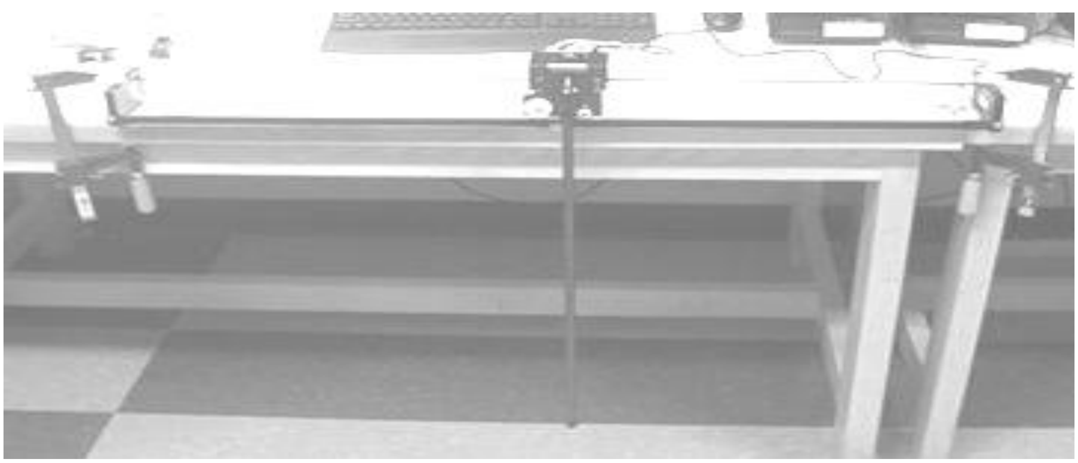

Figure1.1: An Inverted Pendulum model in non-functional state

The inverted pendulum is an intriguing subject from the control point of view due to their intrinsic non-linearity. The main concern is to balance a pole on a mobile platform that can move in only two directions; left or right. The inverted pendulum is related to rocket or missile guidance, where thrust is actuated at the bottom of a tall vehicle. The largest implemented use is on huge lifting cranes on shipyards. When moving the shipping containers back and forth, the cranes move the box accordingly so that it never swings or sways. It always stays perfectly positioned under the operator even when moving or stopping quickly.

Another way that an inverted pendulum may be stabilized, without any feedback or control mechanism, is by oscillating the support rapidly up and down. If the oscillation is sufficiently strong (in terms of its acceleration and amplitude) then the inverted pendulum can recover from perturbations in a strikingly counterintuitive manner.

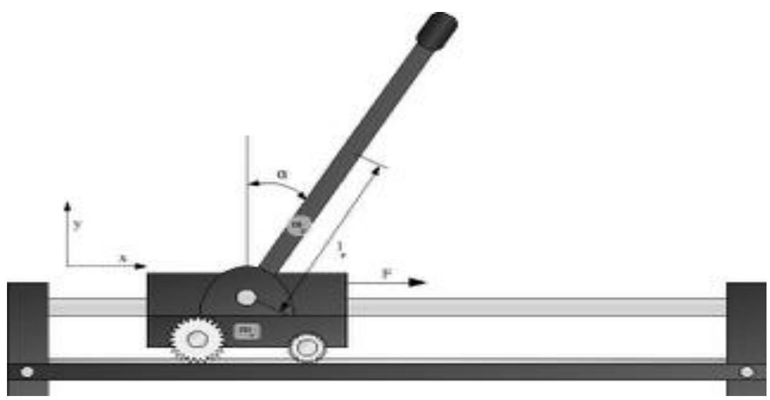

Figure 1.2: The movement of an inverted pendulum

Inverted pendulum system is a nonlinear unstable system, an ideal experiment platform for teaching control theories and conducting various control experiments. Many abstract control concepts, such as the stability and the controllability of a control system, can all be shown visually through the inverted pendulum system. In addition to educational purposes, an inverted pendulum is also a research area for many researchers of modern control theories.

1.2 Objectives

The objectives of this project are:

i) To synthesis the mathematical model of an Inverted Pendulum based on the K. Ogata, 1978 modelling.
ii) To develop the fuzzy logic control strategy to restrain the system‟s cart displacement and rod angle.
iii) To develop the mathematical model of sliding mode controller to restrain the system‟s cart displacement and rod angle.
iv) To run a simulation for both developed control strategies in Matlab Software.
v) To compare the both control strategies in terms of the cart displacement and rod angle pattern as well as other differences.

1.3 Problem Statement

It is virtually impossible to balance out an inverted pendulum without applying external force into the system. The balancing of an inverted pendulum by moving a cart along a horizontal track is a classic problem in the area of control. They are often useful to demonstrate concepts in linear control such as the stabilization of unstable systems.

The problem involves a cart – moving forward and backward – and a pendulum – hinged to the cart at the bottom of its length so that it moves in the same plane as the cart. The pendulum mounted on the cart is free to fall and oscillate along the cart‟s motion axis. A control system is needed to keep the pendulum upright and balanced.

Figure 1.3: An inverted pendulum on its centre

This problem comprises a simple coupled system. If the pendulum starts off-centre, it is prone to fall immediately. Even if it starts centre, once the cart moves, it would triggered to be off-centre and cause the pendulum to fall. In stabilizing this circumstance, such to keep the pendulum in upright position, a control strategy must be applied.

1.4 Work Scope

During the project, a mathematical representation of inverted pendulum will be synthesized based on the K. Ogata, 1978 modelling. An analysis on the difference of linear and nonlinear equations will also be done in order to have a deeper understanding on the characteristics of the system.

Then, control strategies for both fuzzy logic and sliding mode will be developed to restrain the system"s cart displacement and rod angle.
A simulation using the MATLAB Software will be done later on the project to validate the effectiveness of the control strategies. Finally, a comparison of both control strategies in terms of the cart displacement and rod angle pattern as well as other differences will be done to determine the better control strategy.

1.5 Project Methodology

To ensure a successful outcome in the project, the project objectives shall be achieved first. The flow chart below shows the method that will be done step by step until the goal of the project is achieved. There are four phases involved during this project"s execution:

i) First Phase : Literature Review

ii) Second Phase : Mathematical Modelling and control strategy development

iii) Third Phase : Simulation and Analysis

iv) Fourth Phase : Thesis Writing

i) First Phase : Literature Review

- Gather the information about the project via internet, journals, magazines, published work and reference books.
- Study of the software implementation (Matlab).
- Do research to know more details about fuzzy logic controller and sliding mode controller.

ii) Second Phase: Mathematical Modelling and control strategy development

- Synthesize the mathematical model of an Inverted Pendulum based on the K. Ogata, 1978 modelling.
- Simulate the passive system for linear and non-linear validity
- Develop the fuzzy logic control strategy.
- Develop the mathematical model of sliding mode controller.

iii) Third Phase : Simulation and Analysis

- Simulate the inverted pendulum system with controllers separately.
- Analyze the control of cart displacement and rod angle on the inverted pendulum system.

iv) Fourth Phase: Thesis writing

- State all the ideas concentrated regarding to this project.
- Show flow of ideas during the implementation of this project.
- State the project conditions (from the beginning until the end of the project).

CHAPTER II

LITERATURE REVIEW

2.1 Introduction

The literature review undertaken focus on understanding the background and application of inverted pendulum system, mathematical modelling, control and other projects of similar nature.

2.2 Background

The inverted pendulum is a classic example of a non-linear control topic which is studied frequently with reference to design, implementation and development of control. It appears in undergraduate control textbooks such as K. Ogata (1978) where it is used as an example of how to mathematically describe physical systems.

2.3 Present Applications

Inverted pendulum is currently used as teaching aids and research experiments. Quanser (2004), a supplier of educational and research based equipment produce modular systems which can be configured as single or double inverted pendulum. The range offers both rotary and linear version. Many other researchers have also built their own inverted pendulum systems such as Åström and Furuta in 1996 to suit their investigations.

Figure 2.1: An Inverted Pendulum model offered in the market.

2.4 Inverted Pendulum Configurations

The simplest controllable inverted pendulum would consist of a pendulum link directly coupled to a motor shaft (Dorf and Bishop, 1998). This configuration could be controlled open-loop with the use of a stepper motor. However, it is deemed too simple for further consideration. Therefore, the simplest controllable inverted pendulum system that shall be considered must have at least two degrees of freedom, one for the position of the pendulum base and the other for the pendulum angle. For two degrees of freedom, the pendulum base is restricted to only one dimensional movement. The angle has to also vary in only one dimension. For higher degrees of freedom, either more single degree of freedom links are added, or the existing links are allowed to move in multiple dimensions.

In the linear case, a motor is used to move a cart along a straight track. The pendulum is attached to the cart by a pin joint. The axis of rotation of the pendulum link about the pin joint is horizontal and perpendicular to the cart‟s direction of travel. The input to the system is the force applied to the cart, via the motor. Full derivation of the systems‟‟ dynamics for a linear inverted pendulum can be found in Dorf and Bishop (1998) and Franklin (2002).

2.5 Control Methodology

In general, a Control System is a collection of electronic devices and equipment which are in place to ensure the stability, accuracy and smooth transition of a process or a manufacturing activity. It takes any form and varies in scale of implementation, from a power plant to a semi-conductor machine. As a result of rapid advancement of technology, complicated control tasks accomplished with a highly automated control system.

Besides signal interfacing to the field devices (such as operator panel, motors, sensors, switches, solenoid valves and etc.), capabilities in network communication enable a big scale implementation and process co-ordination besides providing greater flexibility in realizing distributed control system. Every single component in a control system plays an important role regardless of size.