CONTROL OF 2 DIMENSIONAL INVERTED PENDULUM USING MATLAB

FARHANA BT ABD RAZAK

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

UNIVERSITI TEKNIKAL MALAYSIA MELAKA (UTeM)

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Alamat Tetap:
75, JALAN EMAS SURIA,
TAMAN EMAS SURIA,
08000 SUNGAI PETANI, KEDAH
TARIKH: 5 MEI 2008

Cop Rasmi: SYAMIMI BINTI SHAMSUDDIN
Pensyarah
Fakulti Kejuruteraan Pembuatan
Universiti Teknikal Malaysia Melaka
Karung Berkunci 1200 Ayer Keroh
75450 Melaka

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I hereby, declared this thesis entitled "Control of a 2 Dimensional Inverted Pendulum using Matlab" is the results of my own research except as cited in references.

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APPROVAL

This Bachelor's Project submitted to the senate of UTeM and has been accepted as fulfilment of the requirement for the Degree of Bachelor of Manufacturing Engineering (Robotics and Automation) with Honours. The member of the supervisory committee is as follow:

………………………………………….

Mrs Syamimi bt Shamsuddin
Project Supervisor
Faculty of Manufacturing Engineering

ABSTRACT

The problem of balancing an inverted pendulum has been a benchmark problem in demonstrating various control design techniques. The principal reasons for its popularity are its nonlinear and unstable characteristics. This project presents the design and simulation of two dimensional inverted pendulum system. The design of the system is done in MATLAB environment. The selection of the controller is the core of this study. PID controller has been chosen as the generic control loop feedback to control the system. In the simulation of inverted pendulum, PID controller is used to control both the position of the cart and the pendulum and also the pendulum angle to ensure the pendulum stands in upright position when the simulation is running. The design of the system is implemented using Simulink block diagram. From the working simulation of inverted pendulum, analysis for the factors contributing in stability of the system is carried out. The analysis covers the parameters of the system, PID controller simulation, set point method and stability of the system. Full working simulation was not able to carry out due to motion equation error but analysis is done using existing data from Simulink environment. The best combination of PID controller and the lowest settling time give the best result for inverted pendulum stability.

ABSTRAK

Masalah keseimbangan bandul *inverted pendulum* telah menjadi satu masalah utama dalam mendemonstrasikan kepelbagaian teknik kawalan rekabentuk. Sebab utama masalah ini menjadi kebiasaan adalah kerana sifatnya yang tidak linear dan tidak stabil. Ianya amat bersesuaian dgn kawalan ujian disebabkan oleh ketidakstabilan dan ketidak linear yang amat tinggi. Projek ini mewakili rekabentuk dan simulasi sistem *inverted pendulum* yang mempunyai dua dimensi. Rekabentuk sistem ini telah digunakan didalam perisian MATLAB. Pemilihan kawalan amat penting di dalam proses ini. Sistem kawalan PID telah dipilih sebagai sejenis kawalan lingkaran tindak balas di mana ianya telah digunakan meluas di dalam sistem kawalan kejuruteraan . Di dalam simulasi *inverted pendulum* ini, alat kawalan PID berfungsi sebagai pengawal kedudukan tapak dan juga *pendulum*. Selain itu juga ia berfungsi untuk mengawal sudut *pendulum* itu untuk memastikan *pendulum* itu berdiri dalam keadaan yang betul ketika simulasi dijalankan. Rekabentuk sistem ini telah digunakan dengan menggunakan blok diagram *Simulink.* Daripada simulasi *inverted pendulum* yang dijalankan, analisis bagi mencari faktor yang mempengaruhi kestabilan sistem turut dilakukan. Analisis ini merangkumi parameter sistem, simulasi alat kawalan PID, kaedah *set point* dan juga kestabilan sistem. Simulasi sistem tidak dapat dijalankan disebabkab terdapat ralat dalam persamaan pergerakan, tetapi analisis masih dijalankan dengan menggunakan keputusan data yang sedia ada dalam *Simulink*. Kombinasi terbaik kawalan PID dan masa kestabilan yang terendah memberikan keputusan yang terbaik untuk pengimbangan sistem.

DEDICATION

For My beloved mother and father

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Bismillahirrahmanirrahim…

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Farhana Bt. Abd Razak

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LIST OF ABBREVIATIONS, SYMBOLS, SPECIALIZED NOMENCALTURE

ANN	-	Artificial Neural Network
DOF	-	Degree of Freedom
FLC	-	Fuzzy Logic Controller
IP	-	Inverted Pendulum
K_p	-	Proportional Gain
K_i	-	Integral Gain
K_d	-	Derivative Gain
MATLAB	-	Matrix Laboratory
NN	-	Neural Network
PD	-	Proportional Derivative
PI	-	Proportional Integral
PID	-	Proportional Integral Derivative
1D	-	One Dimensional
2D	-	Two Dimensional
3D	-	Three Dimensional

CHAPTER 1

INTRODUCTION

1.1 Background

Research in the field of science and technology is widening through out the world. Its aim is to produce products that are able to reduce human energy in doing work. All researches in this field also aim to investigate phenomena that occur in the engineering field. Malaysia is among the countries that is actively involved in the field of research concerned which the hope that this country can contribute to the use of sophisticated technology. One of the continuous researches that is being undertaken in the engineering field is as the control of inverted pendulum.

Extensive research on the balancing of inverted pendulum has been done through out the world using various techniques. Based on the research, scientist found that inverted pendulum is one of the well known example used to illustrate various control techniques. This system is widely applied in area such as rocket control, crane operation, and antiseismic control of buildings. The inverted pendulum is an example of an unstable non linear system.

Non-linear control is a sub-division of control engineering which deals with the control of non-linear systems. The behavior of a non-linear system cannot be described as a linear function of the state of that system or the input variables to that system. A nonlinear system is one whose behavior cannot be expressed as a sum of the behaviors of its parts. In technical terms, the behavior of nonlinear systems is not subject to the principle of superposition. Non-Linear system is investigated with respect to the dynamics of the inverted pendulum. The inverted pendulum is an example of an unstable highly non-linear system. This problem has been a research interest of control engineers. Consequently, it has received much attention, as it is an extremely complex and challenging control problem.

The inverted pendulum system is a Control Engineering problem that is used in universities around the world. It is a suitable process to test prototype controllers due to its high non-linearity and lack of stability. The system consists of an inverted pole hinged on a cart which is free to move in the x-axis direction. The term “inverted” means opposite position and “pendulum” means a weight hung from a fixed point.

1.2 Problem Statement

The problem of balancing an inverted pendulum has been a benchmark problem in demonstrating and motivating various control design techniques. The principal reasons for its popularity are its nonlinear and unstable characteristics, uncertainty in friction terms, lack of state variable measurements, and the easy way disturbances are introduced in the process. In addition, the problem is also representative of some other well-known control problems, such as that rocket taking off, cranes with hanging loads, and the apparatus also has the attraction of inexperienced people who attempt to control using hand motion. The inverted pendulum is among the most difficult systems to control in the field of control engineering. There is a need for a control method which addresses the non-linearity of an operating system, incorporating an adaptation capability.

Due to its importance in the field of control engineering, it has been a task of choice to be assigned for students to analyze the inverted pendulum model and propose a linear compensator according to the PID control law in the MATLAB environment.

1.3 Scope

The scope of this final year project is to design a two dimensional inverted pendulum using MATLAB software. This project will focus on the design of the inverted pendulum controller using PID (proportional integral derivative) close loop system. The design also can able to control the inverted pendulum in the upright position when the working control model is achieved. PID controller needs to stabilize the angle of inverted pendulum in the simulation environment.

1.4 Objectives

The aim of this project is to design and build a working control model that can balance two dimensional inverted pendulum in an upright position by using MATLAB software. Throughout this project, the following objectives will be achieved:

a) To conduct literature study on existing controller designs for the inverted pendulum.
b) To design and build a control model for 2 dimensional inverted pendulum using PID controller.
c) To build a working simulation and make analysis from the control model in MATLAB environment.

1.5 Brief History of Inverted Pendulum

The simple linear pendulum has long proved a useful model for more complicated physical systems, and its behavior in the small-amplitude limit provides a realistic yet solvable example for students in introductory classes. While the force-free, frictionless pendulum can be solved exactly for all amplitudes in terms of elliptic integrals, the solution is hardly illuminating, rarely found useful, and when damping and external driving are included, the equations of motion become intractable. With the advent of desktop computers, however, it has become possible to study in some detail the rich nonlinear dynamics of the damped, force driven pendulum and gain significant insight into its sensitivity to initial conditions for certain values of the system parameters (Chye, 1999).

In 1581, Galileo, a physicist, began studying at the University of Pisa. While at the University of Pisa, Galileo began his study of the pendulum while, according to legend, he watched a suspended lamp swing back and forth in the cathedral of Pisa. However, it was not success until 1602 that Galileo made his most notable discovery about the pendulum. The period (the time in which a pendulum swings back and forth) does not depend on the arc of the swing (the isochronism). Eventually, this discovery would lead to Galileo's further study of time intervals and the development of his idea for a pendulum clock (Helden, 2004).

Early studies of the inverted pendulum system were 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 in open loop configuration. This problem can be compared to the rocket during launch. Here, rocket boosters have to be fired in a controlled manner, to maintain the rocket upright (Chye, 1999).

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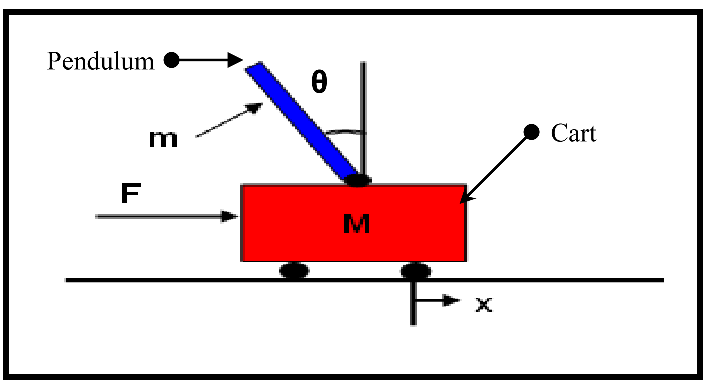
The inverted pendulum is a classic problem in dynamics and control theory and widely used as benchmark for testing control algorithms (PID controllers, neural networks and genetic algorithms). Variations on this problem include multiple links, allowing the motion of the cart to be commanded while maintaining the pendulum, and balancing the cart-pendulum system on a see-saw. The inverted pendulum is related to rocket or missile guidance, where thrust is actuated at the bottom of a tall vehicle. 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 (Jeffers, 2001).



M = mass of the cart
m = mass of the pendulum
F = force applied to the cart
x = cart position coordinate
θ = pendulum angle from vertical

Figure 1.1: Inverted Pendulum (Callinan, 2003)

In 1898, E. Wiechert of Gottingen introduced a seismograph with a viscously damped pendulum as a sensor (Wiechert, 1899). The damping was added to lessen the effects of the pendulum eigen-oscillations. Wiechert's first seismograph was a horizontal-pendulum instrument, which recorded photographically. After a trip to Italy to study seismometers used in that country, he decided to build a mechanically-recording seismograph. For a sensor, he used an inverted pendulum stabilized by springs and frees to oscillate in any direction horizontally (Wiechert, 1904). The seismograph was completed in 1900.

Besides classroom theory and various control design methods, digital control exposure is important to the many practical aspects of implementing a digital control system. This requires a good foundation in control theory as well as knowledge in computer interfacing techniques, system modeling, instrumentation and digital signal processing. The modeling of inverted pendulum shall be created in MATLAB.

1.6 Project Schedule for Final Year Project

Table 1.1 shows the Gantt chart for the study which will be carried out through a two semester period.

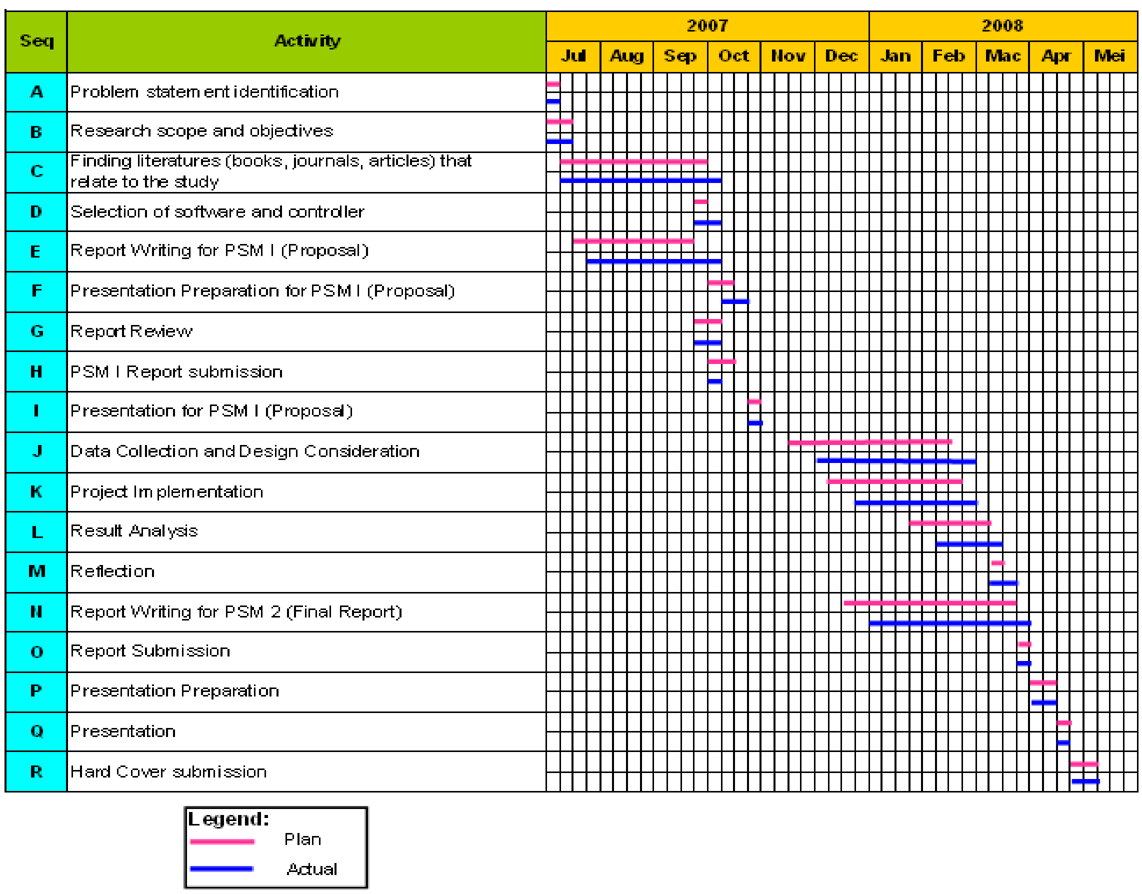


Table 1.1: Project Schedule for Final Year Project