BALL AND BEAM CONTROL SYSTEM DESIGN USING MICROCONTROLLER

SHEIKH MUHAMMAD HAFIZ FAHAMI BIN ZAINAL

UNIVERSITI TEKNOLOGI MALAYSIA

This thesis is especially dedicated to my dearest father, mother and family
for their love, blessing and encouragement

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ABSTRACT

This project report will present a ball and beam system design using microcontroller. The system consists of two parts. The first part is hardware module and the second part is software module. Hardware module is interfaced with the software module. The ball and beam system is the most popular laboratory model used in control system due to its simple modeling and low in cost. However this system is an open loop unstable system. A ping pong ball will roll on the top of long beam with and acceleration is proportional to the angle of the beam. The ping pong ball may fall down from the beam if the system cannot be control properly. The main objective of the system is to regulate the position of the ball along the beam to its reference position. The main parts in this hardware module are Servo Motor and Sensor. Servo Motor responsible to make the beam moving. Analog distance sensor will detect the range or distance of the steel ball to it reference position. Structure parts are made from aluminum material because less weight and low cost compare to other material such as mild steel and stainless steel where it expensive and heavy in weight. For the software module, it will use microcontroller and this microcontroller must be able to communicate with a PC in order to relay diagnostic and statistic project, and must be able to function in absence of PC. Controller that will be used in this project is Proportional (P) controller and C language will be using to write the programmed using MPLAB software and burn into microcontroller using PIC2 kit software. The main parts in this software module is PIC16F877A, voltage regulator, motor driver for servo motor, boot loader (UIC programmer) and LCD display used to display the characters or current distance.

ABSTRAK

Laporan projek ini akan membicangkan sistem pengimbangan bola di atas pelantar dan ia terbahagi kepada 2 bahagian. Bahagian pertama berkenaan dengan perkakasan sistem dan bahagian kedua berkenaan dengan pengatucaraan dan litar, Sistem ini harus beroperasi sama ada dalam kehadiran computer atau tanpa kehadiran computer. Sistem imbangan bola di atas pelantar merupakan sistem yang biasa digunakan dalam kawalan dan merupakan sistem yang agak murah. Sistem ini merupakan sistem yang tidak stabil. Bola ping pong akan melalui di atas pelantar dan halajunya seimbang pada sudut di pelantar. Bola ping pong akan jatuh jika sistem tidak dapat kawal dengan baik. Objektif utama dalam projek ini ialah memastikan kedudukan bola sama dengan keadaan yang dirujuk atau keadaan yang telah dikenal pasti kedudukan yang sepatutnya. Di dalam projek ini kedudukan bola ping pong harus berada di tengah pelantar. Komponen utama dalam sistem ini ialah motor dan pengesan jarak. Motor digunakan untuk mengerakkan pelantar dan pengesan jarak digunakan untuk mengesan kedudukan atau jarak bola ping pong. Perkakasan dalam sistem ini menggunakan bahan aluminum disebabkan ringan dan murah berbanding dengan bahan seperti besi yang berat dan mahal. Untuk bahagian pengatucaraan dan litar, komponen utama ialah PIC16F877A, pengatur kuasa dan litar kepada motor. Pengatur kuasa digunakan untuk membekal kuasa kepada PIC16F877A dan litar motor digunakan untuk mengawal halaju motor dan arahnya.

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LIST OF SYMBOLS

B_{eq}	-	Total load friction
F	-	Rotational force
I	-	Indentify matrix
I	-	Motor armature current
J	-	Moment of inertia
J_a	-	Motor armature inertia
J_{eq}	-	Total load inertia
K	-	Full state feedback gain
K_c	-	Proportional gain
K_d	-	PID derivative gain
K_g	-	Gear ratio
K_i	-	PID integral gain
K_m	-	Motor Torque constant
K_p	-	PID proportional gain
L	-	Beam length
L_a	-	Inductance in armature coil
R_a	-	motor armature resistance
T_d	-	derivative time
T_i	-	integral time
T_l	-	load torque
T_m	-	torque produced by motor shaft
T_s	-	sampling time
V	-	volts
V_{in}	-	motor input voltages
d	-	lever arm offset
e	-	error

LIST OF ABBREVIATIONS

DC	-	Direct current
DOF	-	Degree of Freedom
P	-	Proportional
PD	-	Proportional Derivative
PI	-	Proportional Integral
PID	-	Proportional Integral Derivative

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CHAPTER 1

INTRODUCTION

1.1 General Introduction

The ball and beam system is one of the basic examples of nonlinear and unstable control system .This system commonly used for control theory verification or control system design and implementation practice. This system getting popular and become an important laboratory models for teaching control system engineering due to very simple to understand as a system and the control technique that can be studied and it cover many important classical and modern design methods. The system also used as a control training tool in many industrial processes and their application.

The ball and beam mechanism consists of a beam and solid ball on it. The ball is rolling free along the beam according to the changing angle of the beam. The beam rotates in the vertical plane driven by a torque usually using servo motor at the side. The required ball position is being control by applying an electrical control signal to the motor amplifier. The position of ball on the beam can measured using special sensor.

The control task is difficult because the ball does not stay in one place on the beam but moves with an acceleration that is proportional to the tilt of beam. In control technology the system is open loop unstable because the system output (ball position) increases without limit for a fixed input (beam angle). Feedback control must be used to keep the ball in a desired position on the beam.

There are so many method and type in designing the model of ball and beam system hardware. Most the ball and beam system using stainless steel material because it looks clean and it using gears to connect to the motor. But in this project, there is no gears will be using and implemented. Most of the structure ball and beam system is too complicated due to connection of gear between gear, motor to the gear and the material using for the structure that is heavy and expensive. In this project, the cost will reduce and the structure of the ball and beam system will be simplified to make it simple and easier in design and modification. There is no gears will be using and implemented, the shaft motor will directly connected to coupling, and this coupling will connected to plate which will move the beam. About software module, the circuit of ball and beam system is design by using proteus software to ensure to correct circuit in designing. Simulate the circuit and then fabricate according to the design. In this project PIC16F877A will be used because it is too familiar using. Other parts are voltage regulator, servo motor driver and LCD display. This software will using MPLAB software and C language programme with the hex file will burn and loaded in PIC16F877A using PIC2kit software. More about software module will be discuss in next chapter.

1.2 Objectives of project

The main objective of this project is to develop a hardware and software module of ball and beam system control by microcontroller with to regulate the position of ball along the beam to its reference position. Begin with researching about how previous model has been design and then design structure and circuit of ball and beam and what material will be using whether it aluminum, mild steel or stainless steel. Indentify the parts or component required such as DC motor, sensor, gears or other that related. Also researching about how to assemble between component and parts to make it properly connected.

The second objective is to design the suitable controller in programmable microcontroller. This microcontroller must be able to communicate with PC in order to relay diagnostic and statistic project and must be able to function in absence of PC. The C language will be using to write the programmed using MPLAB software and burn into microcontroller using PIC2Kit boot

loader. Lastly, the objective is to run the ball and beam system and test the stability of the system. In order to run the system, the interfacing between hardware and software must be correctly interfaced and choosing the right component to connect is important to avoid any error during run and testing the system.

1.3 Scope of Project

For the achievement of the objective, this project will cover the following scopes:

i. Derivation of the Mathematical Modeling

The derivation is based on the Lagrangian equation that comprise from the two types of dynamic equation, which are force equation and torque equation. It was defined from previous study by Hauser et al (1992). From Hauser model, the beam is to rotate by applying a torque to the beam at its centre of rotation and the ball is free to roll along the beam. It is assumed that the ball remain in contact with the beam at all angles, that is in practical terms there exists guides ensuring contact require a restriction on angle and acceleration to ensure contact. It should be noted that it is not the physical behavior of an actual ball and beam, which anyway the equation only approximation

ii. Design and implement hardware and software module of Ball and Beam system.

For hardware module, the servo motor will be placed at the side whether at the left side. The main parts in the hardware are servo motor and sensor. Servo motor will be using and analog distance sensor is using to detect the range or distance ball.

The rubber wheel will be using to connect to the shaft servo motor, and holder of the shaft will be connected to the wheel. The sketching of the ball and beam system will be roughly drawn in the paper before using solid work software for the final sketching in 3 dimensional views. For software module, the circuits are design and simulate using proteus software. After that, the circuit is fabricating according to the design. Main

parts in this circuit are PIC16F877A, voltage regulator, motor driver, and LCD display. MPLAB software is used to write programmed in C language and burn in PIC16F877A using PIC2Kit boot loader.

iii. Design the suitable controller and interfaced it with hardware.

Proportional (P) controller will be using in ball and beam system in programmable microcontroller. The Proportional controller commonly used for control theory verification in most of laboratory and the design base on linearized model. For nonlinear ball and beam system, the control performance is basically sufficient enough and easy to be realized in practical experiment. C language will be using in programmed before burn into microcontroller using PIC2Kit boot loader.

iv. Test and run the ball and beam system.

The stability of the system will be analyzed by test and run the system. In order to run this system, the hardware and software must be interfaced correctly to make sure the system run according to the step and task given. Correct interfacing will avoid the error during test and run.

1.4 Significance and need for study.

Most control problem that meets in practical world are straightforward to control. For the fixed input signal that the output stays more or less constant. An important set of system however are, either by design or nature, unstable and feedback control is essential to make them operate safely. Many modern industrial process and technological system is intrinsically unstable could be used without stabilizing feedback control.

The control of unstable system is critically important to many of the most difficult control problems and must be studied in the laboratory. The problem is that the real unstable system is

usually dangerous and cannot be brought into the laboratory. The ball and beam system was developing to resolve this paradox. It is a simple, safe mechanism and has the important dynamic features of unstable system.

Improving the performance of the ball and beam system has been done whether for hardware and software. By selection the best material considering the weight and choosing the right component or parts according to the requirement will improve the performance of the system.

1.5 Problem Statement.

The ball and beam system is a simple mechanical system which is used fairly difficult control problem. It consists of rigid beam which is free to rotate in the vertical plane around a centre pivot, with a solid ball rolling along the beam. The control problem is to position the ball at desired point on the beam using a torque or force applied to the beam as a control input. The nature of this task may be appreciated by thinking of the ball as a mass sliding on a frictional along the beam.

The position of the ball cannot be controller directly, but only through its acceleration. Thus, it will imply the presences of the two integrators plus the dynamical properties of the beam result in a difficult open loop unstable control problem, which is non- linear system.
This control can be approximated as a linear model. Thus, linear feedback control such as Proportional (P) control can be applied and the stability analysis is based on linear state model or transfer function. Approximate input output linearization used state feedback to linearize ball and beam system first, then tracking controller based on the approximated system can be stabilize the ball and beam system.

1.6 Thesis Outline

This thesis consists of seven chapters. It begins with the introductory chapter. This chapter gives brief description of the problem and background of the ball and beam system, objectives of project and scope of project.

Chapter two discusses the literature review and other related work from previous existing modeling paradigm and controllers for stabilizing the ball and beam system.

Chapter three includes the setup of the ball and beam system. It contains the overview of the system, components used, and derivation of mathematical model of ball and beam system.

Chapter four includes a discussion of the controller design of ball and beam system with some introduction of PID controller.

Chapter five describe about hardware module for ball and beam system design. Includes are design, mechanical parts such as sensor, motor and other that related.

Chapter six describe about hardware module for ball and beam system with includes the circuit diagram and components that used in the circuit such as voltage regulator, PIC and other that related. Also discuss about interfacing with hardware module.

Final chapter is chapter seven that describe the overall conclusion and future work for ball and beam system design.

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