UNIVERSITI TEKNIKAL MALAYSIA MELAKA

MODELLING AND CONTROL DESIGN OF A BALL AND BEAM EDUCATIONAL TOOL

This report is submitted in accordance with the requirement of the Universiti Teknikal Malaysia Melaka (UTeM) for the Bachelor of Electrical Engineering Technology (Automotion And Robotics) with Honours.

by

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I hereby, declared this report entitled Modelling And Control Design Of A Ball And Beam Educational Tool is the results of my own research except as cited in references.

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APPROVAL

This report is submitted to the Faculty of Electrical and Electronic Engineering Technology of Universiti Teknikal Malaysia Melaka (UTeM) as a partial fulfilment of the requirements for the degree of Bachelor of Electrical Engineering Technology (Industrial Automation & Robotics) with Honours. The member of the supervisory is as follow:

Signature: …….

Supervisor : Ts. Dr. Syed Najib Syed Salim

ABSTRAK

Sistem bola dan pelantar adalah peralatan asas makmalyang dapat berfungsi sebagai alat pendidikan untuk teori kawalan pembelanjaran, idea utama untuk project ini adalah untuk mengembangkan sistem bola dan pelantar dengan mempertimbangkan faktor bukan linear dengan pengawalan Proportional Integral Derivative (PID) untuk mengawal kedudukan bola. Sistem ini menyambung dengan mikrokontroler Arduino untuk menerima isyarat kedudukan bola dari sensor ultrasonik (HC-SR04) untuk membandingkannya dengan kedudukan yang diinginkan dan nyata menjadi isyarat kawalan. Algoritma PID yang dibina dalam Arduino digunakan untuk memproses pembezaan isyarat antara kedudukan yang diinginkan dan yang nyata menjadi isyarat kawalan. Arduino menghantar isyarat kawalan ke servomotor DC yang berputar untuk mengubah kedudukan bola dan jarak yang diperlukan. Program perisian MATLAB digunakan untuk membangun respons sistem instan dari Arduino yang berinteraksi dengan komputer untuk mengidentifikasi ciri system yang mempunyai nilai parameter pengawalan yang berbeza untuk memilih parameter yang dapat mencapai prestasi sistem yang terbaik. Pelaksaan perkakasan adalah suatu keharusan untuk memahami kestabilan sistem pengimbangan bola dan pelantar.

ABSTRACT

Ball and beam system was a basic laboratory equipment that can be act as educational tool for learning control theory. The main idea of this project is to develop a ball and beam system considering nonlinear factor by using Proportional Integral Derivative (PID) controller to control the ball position. The system was interface with Arduino microcontroller to receive the signal of ball position from ultrasonic sensor (HC-SR04) to compare it with desired and real position into control signal. The PID algorithm that built in Arduino was used to process the difference in signal between desired and real position into control signal. Arduino sends a control signal to the DC servomotor that rotates to change the position of the ball and the required distance. MATLAB software program was used to construct instant system response from Arduino interfacing with the computer in order to identify system characteristics that have different controller parameter values in order to choose parameter parameters that achieve the best system performance. Hardware implementation was a must in order to understand the stability of ball and beam balancing system.

DEDICATION

To my beloved parents

Thank you for all the unconditional support along my project period. I am grateful to have you being by my side. Thanks for the concern to support me complete my bachelor's degree Project (BDP).

To my beloved Supervisor

Thanks for your patient and valuable knowledge throughout my bachelor's degree Project (BDP). I am very appreciate for your supports.

To my dear Friends

Thank you for all the supports throughout the project.

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CHAPTER 1

INTRODUCTION

1.1 Ball And Beam System

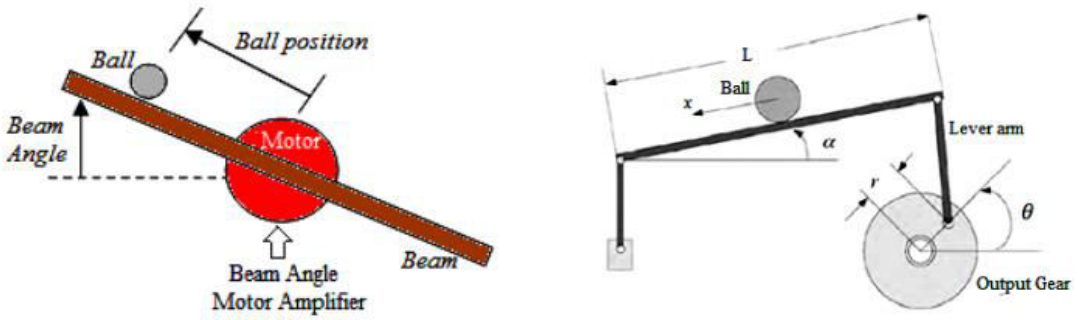
The ball and beam system which is use to balance a ball on a tilting beam which can be rotated alongside a ball moving back and forth on top of the beam by a servo or electric motor. This technique has been studied for years and control methods in the literature are explained. A wide range of interconnected fields such as electrical machine, drives, control electronics and software for an industrial application can be practically implemented in advanced controlled systems. The education method on ball and beam provided here acted as an educational tool that allows students to work in all areas. The system consists of a ball, a beam, a servo motor, ultrasonic sensors , smart drive and a host PC. The ball and beam system educational tool was an influential laboratory tool that help engineering student to be more understand on analyzation in balancing control system. It can be used to test, analyze, educate and demonstrate the effect of different control strategies, with a simple , easy-to-understand and user-friendly interface allowing users to manipulate a machine, collect and output data and save space (Salem, 2013).

This educational tool involves the simulation, analysis and control by the use of Matlab /Simulink and experimental hardware of the ball and beam system. Study stability of control system was able to be apply on varies application such as balancing of good carried by mobile robot, lift and spacecraft position control (Ding, Liu and Wang, 2019). Another advantage for study stability by using ball and beam balancing

system is due to it is quite simple to build up and easy understanding of mathematical model.

The common structure of the ball and beam balancing system is a servomotor attached to the beam so that the motor shaft can monitor the beam angle with the assists of ultrasonic sensor in order to enable alignment and troubleshooting. There are generally two type of configuration of the system model which are the lever arm which is directly connected to the centre of the beam or to the motor shaft at the end of the beam. The first configuration is shown as Figure 1.1(a) below. The beam was supported at the centre and the oscillation against the central axis.

The second configuration is shown as Figure 1.1(b) below. It demonstrates that the beam was supported at the both side of the system. One side was supported by lever arm that connected to the output gear of the motor and another side is fixed point that acted as a pivot. This type of configuration was more difficult and more considering on the mechanical part. This is because there was lots of factor that will affect the performances of the system so it is also increases the difficulty of the mathematical modelling of the system.



(a) (b)

Figure 1.1 (a) Beam supporting point at centre (b) Beam support at both side

At the side of application and scope, this study describes the concept and implementation of a ball and beam model for the assessment of control algorithms and Proportional, Integral and Derivative (PID) controller. The linear feedback such as PID control is apply to study ball and beam stabilization and the result can be analyse by state-space model and transfer function. There are also some advanced controllers such as fuzzy control and neutral network control that can be apply in ball and beam balancing system.

Using Arduino Uno along with a dc servo motor and ultrasonic sensor, the instruction was given by coding that we implement in Arduino IDE. Acceleration of the ball was detected to control its to be in desired position, this is due to the position of ball cannot be measured and control directly. People who related to control system fields will learn how to analyse and design control systems with the experiment platform through ball and beam system as they are new to this field.

1.2 Project Objective

The purpose of this project was listed below:

a) identify the mathematical model that represents a ball and beam system
b) design a proportional plus integral and derivative controller (PID) for ball and beam system.
c) analyse the system performance of ball and beam balancing system.

1.3 Problem Statement

There are many ways to control most of the problem that faced in laboratory practical world. Ball and beam system presents a challenge in the design and control of

the system control stability. Basic concept within this control system can also be used in many industrial applications, such as precise location control in the production line. The concern is that the actual unstable system is typically unsafe and cannot be put in the laboratory. In order to achieve stability, PID controller plays a main role and it was implemented into the system. It is important that ball and beam system to be act as an educational tool to give guidance to the people who are related to control system field. This may help to decrease the rate of accident occur due to the lack of knowledge about PID controller in order to control the stability.

1.4 Scope of the project

This project focuses on finding the mathematical modelling of the ball and beam balancing system in order to act as an educational tool for giving guidance about stability to society. Next, PID controller for ball and beam balancing system was designed to achieve stability. Besides that, system performances of ball and beam system was analysed by using MATLAB. For hardware implementation, Arduino Uno, servo motor and ultrasonic sensor were used to be interfaced the system. For software simulation and analysation for the system, MATLAB software was selected.

1.5 Report Outline

The layout for the thesis is as follow:

Chapter 1 Introduction: This chapter discusses about the background of the project. Type of configuration of the system are reviewed. Objective, problem statement and scope of the project are part of this.

Chapter 2 Literature review: This chapter discusses about the previous researcher and project regarding the title. The various techniques that used to applied on the system are also reviewed. Short summary and some proposal that to improve the system was described.

Chapter 3 Methodology: This chapter focuses on the methodology of the project. It was described about the research flow and method used in this project. Mathematical modelling of the system was interpreted in this chapter.

Chapter 4 Result and Analysis: This chapter demonstrates about the finished experimental hardware of the ball and beam balancing system. Calibration of the parts of the system was reviewed. Besides, the analysis based on the system performances will be discussed in detail. The performances of the results will be compared by various variable. The performances of the technique used in this project was clearly examined by simulation and experimental work.

Chapter 5 Conclusion and Recommendation: This chapter describes about the summary of this project, the objective and scope of the project were clearly stated being achieved in this chapter. Future work and recommendation also provided at the end of the chapter.

CHAPTER 2

LITERATURE REVIEW

This chapter described about the system model that done by previous researchers. Several type of controller design such as Proportional Integral Derivative (PID) controller, Fuzzy PID controller, Coefficient Diagram Method (CDM) and other techniques are part of this.

2.1 System Model

There are a lot of system model of ball and beam system that had been developed by numerous researchers before. Some of them are described in this section.

Figure 2.1 ‘ Ball and balancing beam’ built by Berkeley Robotics Laboratory (Arroyo 2005)

One of the system model that have been done was ‘Ball and balancing beam’ that built by Berkeley Robotics Laboratory. The device named the' Ball on Balancing Beam' was built by Arroyo (2005) as shown in figure 2.1(Wang and Australia, no date).

In order to measure ball position, the system used a resistive wire sensor. A DC motor was used with a gear reducer and the system was controlled through the PD controller. The system is easy and simple to install, and the negative parts of this system include the acrylic beam, which might be too fragile for a sudden impact. Furthermore, the beam tilt angle has not been calculated or monitored while the direction of the ball was controlled by the PD controller.

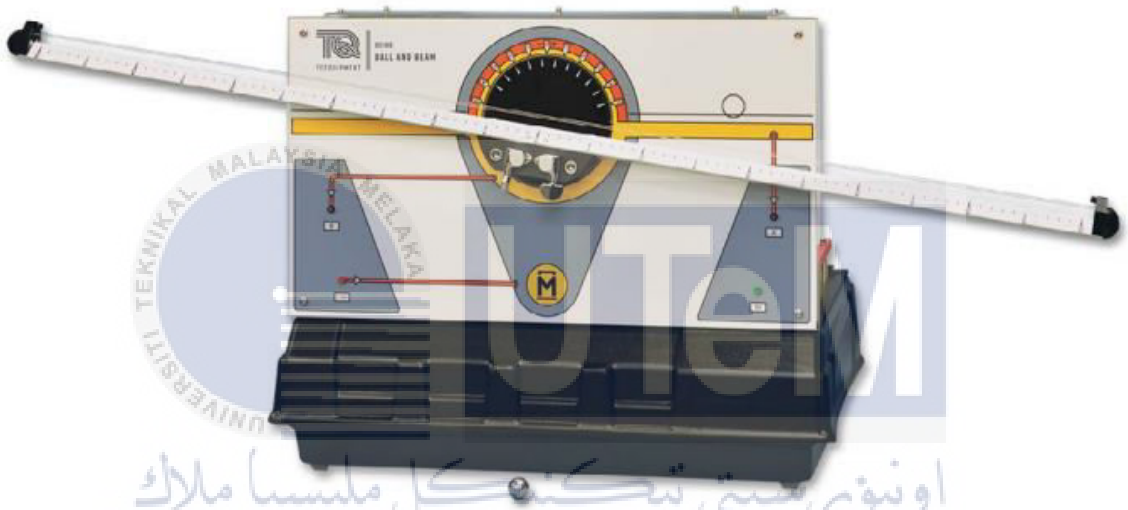


Figure 2.2 CE106 Ball and beam system.TQ (Tecquipment) Education and Training Ltd

The second system model of ball and beam balancing system was CE106. TQ (Tecquipment) Education and training Ltd. designs the CE106 ball and beam system, and control demonstrations are carried out using actual systems models developed by Peter Wellstead.(Edalati, no date). This is central pivot, which ensures that the beam at the center is balanced. It is used as a guide to simulate instable system control. The problem of rocket or missile stability during launch is overcome by the use of a ball and beam system. This system has two main sections of control. First, the beam angle must

be controlled by managing the voltage entering the motor to ensure that the motor speed stays at the required speed. Then the position of the ball is controlled by using this beam angle as the input.

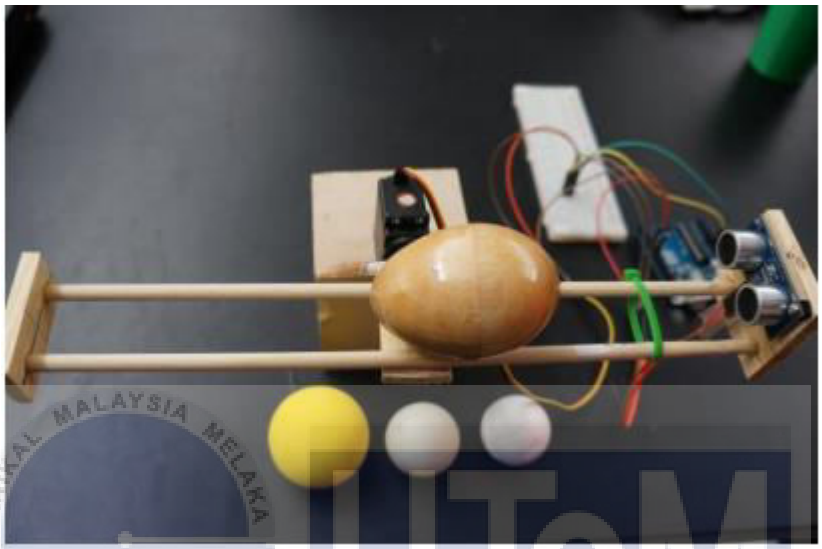


Figure 2.3 Ball Beam Balancer (Gao *et al.*, 2015)

In order to keep a ball balance on the beam by using the Arduino (UNO Rev 3.0), the Parallax Ping (Parallax Ping) ultrasonic sensor and the servo motor (HS-645MG), the ball beam balancer has been designed to create a control algorithm to control the beam angle (Gao *et al.*, 2015). The author used different size of ball to determine the vary coefficient. This project faced serious shaking problem due to multiple reason such as the different mass of the ball and vary in friction between the ball and the rod. In practice, many uncertain factors affect the actual system, and the PID test results are usually different from the theoretical results.