# CONTROL OF CART-BALL SYSTEM USING STATE FEEDBACK AND FUZZY LOGIC CONTROLLER

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To all my beloved family. Thank for all your support .

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# ABSTRACT

A cart-ball system and the associated control design is an excellent platform for testing and evaluating different control techniques since such a system is an open-loop unstable system and demonstrates some basic concepts in control being nonlinear, multivariable and non-minimum phase. Industrial applications of such type of systems can be found in, for example, precise position control in production line. To control such a system, a controller should be designed to adjust the cart in a desirable manner through a DC motors. The cart position and ball angle form vertical are measured variables and manipulated variable is the horizontal force acting on the cart. The cart-ball mathematical model is derived and then linearized to be a linear model. The whole system then has been model in state space equation. The controller design is based on the theory of state feedback control approach and fuzzy logic control approach. Experimental results presented are useful for demonstrating practical aspects of the analysis. Furthermore, the cart-ball control system developed, is ideal for demonstrating the design and hardware implementation of optimal controllers based on modern control theory.

# ABSTRAK

Sistem bebola muatan dan rekabentuk kawalan yang berkaitan adalah platform terbaik untuk menguji dan menilai pelbagai teknik kawalan untuk sistem tidak stabil gelung terbuka dan memperlihatkan beberapa konsep asas dalam kawalan tidak linear, berbilang pembolehubah dan fasa bukan minimum. Aplikasi industri untuk sistem berkenaan dapat dilihat, seperti kawalan kedudukan tepat dalam barisan pengeluaran. Untuk mengawal sistem sebegini, pengawal hendaklah direkabentuk supaya melaraskan muatan ke kedudukan yang bersesuaian mengunakan motor DC. Kedudukan muatan dan sudut bebola dari menegak adalah pembolehubah yang boleh diukur dan pembolehubah yang boleh dimanupulasi adalah daya mendatar yang bertindak keatas muatan. Model matematik bebola muatan diterbitkan dan dilinearkan menjadi model linear. Seluruh sistem dimodel dalam bentuk persamaan “state space”. Rekabentuk pengawal adalah berdasarkan teori kawalan “state feedback” dan “fuzzy logic”. Keputusan eksperimen yang dilampirkan adalah berguna untuk demonstrasi analisis aspek praktikal. Tambahan lagi sistem kawalan bebola muatan yang dibangunkan adalah ideal untuk demonstrasi rekabentuk dan perlaksanaan perkakasan pengawal optimal berdasarkan teori kawalan moden.

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| | |
|---|---|
| $R$ | Cart radius of the arc |
| $M$ | Cart weight, including equivalent mass of motor and transmission |
| $y$ | Cart position |
| $F$ | Cart driving force |
| $r_1$ | Ball radius |
| $r$ | Ball rolling radius |
| $\psi$ | Ball rolling angle [radian] |
| $\varphi$ | Ball angular deviation [radian] |
| $m$ | Ball weight |
| $I$ | Ball moment of inertia |
| $V$ | Ball vertical reactive force [N] |
| $H$ | Ball horizontal reactive force [N] |
| $U$ | Motor voltage |
| $U:F$ | Motor transmission ratio |
| g | Gravity |

# LIST OF ABBREVIATIONS

| | |
|---|---|
| DC | Direct Current |
| ISL | Is Left |
| ISM | Is Middle |
| ISR | Is Right |
| MVL | Move Left |
| SST | Stay Still |
| MVR | Move Right |
| PHL | Push Hard Left |
| PHR | Push Hard Right |
| SOC | Self Organizing Controller |

# CHAPTER 1

# INTRODUCTION

## 1.1 Introduction

The ball-balancer, or cart-ball system, demonstrates some basic concepts in control since it is nonlinear, multivariable and non-minimum phase. The control objective is to balance the ball on the top of the arc and at the same time place the cart in the desire position. It is basically an inverted pendulum problem with little difference in term of its physical configuration.

The whole system is needed to be modeled first by using a state space equation. It has been found that this system results a non linear model. From this nonlinear model, the linearization process has to be done. After the linearized model has been acquired, the next task to do is to control the cart-ball system until it become stable.

In this project, the main task is to control the angular deviation $\varphi$ from the vertical of the ball and the position of the cart $y$. If the angular deviation $\varphi$ and cart position $y$ is equal is equal to the set point, it can be concluded that the designed controller is successful in controlling the ball angular deviation $\varphi$ and cart position $y$ system become stable. In this project, there are 2 types of controllers that have been used. First, it is the Pole Placement technique and another one is Fuzzy Logic Controller.

The performance of both controllers in controlling the cart-ball system is evaluated through extensive computer simulation using MATLAB/SIMULINK

## 1.2 Objective of the project

The objectives of this project are as follows:

(i) To formulate the complete state-space representation of Cart-Ball System.

(ii) To design a controller using Fuzzy Logic approach.

(iii) To compare the performance of the Fuzzy Logic Controller with the pole placement technique via simulation result.

## 1.3 Scope of Project

The work undertaken in this project is limited to the following aspects:

(i). The nonlinear mathematical model of cart-ball system based on Jan Jantzen [1] and the linear mathematical model is derived afterwards.

(ii). Simulation work using MATLAB/SIMULINK as a platform to prove the effectiveness of the both designed controller.

(iii). Comparative study between the Fuzzy Logic Controller and pole placement technique will be done.

## 1.4 Research Methodology

The research work undertaken in the following five development stages:

(i) The development of linear mathematical model for cart-ball system.

(ii) The design of controller base on pole placement technique.

(iii) The design of Fuzzy Logic Controller.

(iv) Perform simulation using MATLAB/SIMULINK for pole placement and Fuzzy Logic Controller.

(v) Comparative study of both controllers is done.

## 1.5 Layout of Thesis

This thesis contains six chapters. Chapter 2 contains a brief introduction of cart-ball system. The derivation of the mathematical model, which is a nonlinear model of the cart-ball system, is also presented. The linear mathematical model of the system is derived and then transforms into the state space representations.

Chapter 3 presents the brief introduction of pole placement technique.

Chapter 4 presents the brief introduction of fuzzy logic controller.

Chapter 5 presents both the results of pole placement technique and fuzzy logic controller. For every controller there will be two graphs presented. The first one is the ball angular deviation and the other one is the cart position. At the end of this chapter, the comparison between the pole placement technique and fuzzy logic controller is done.

Chapter 6 presents the analysis and discussions about the results obtained in the previous chapter.

Chapter 7 concludes the work undertaken, suggestions for future work are also presented in this chapter.