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Ball and beam controller using PIC / Muhamad Zamri
Sukarman.

BALL AND BEAM CONTROLLER USING PIC

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Bachelor in Mechatronic Engineering

April 2009

“I hereby declare that I have read through this report and found that it has comply the partial fulfillment for awarding the degree of Bachelor of Mechatronic Engineering”

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Date : April 2009

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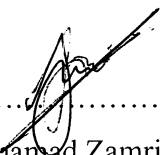
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**This report is submitted in partial fulfillment of requirements for the degree of bachelor
in mechatronic engineering**

**Faculty Of Electrical Engineering
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APRIL 2009

“I hereby declare that this report is a result of my own work except for the excerpts that have been cited clearly in the references.”

Signature : 

Name : Muhamad Zamri bin Sukarman

Date : April 2009

For my beloved father and mother
Hj. Sukarman bin Baharuddin and Hjh. Rosna bt. Anwar
In appreciation of supported and understanding

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In the name of Allah the most Beneficent and Merciful. A deep sense of thankfulness to Allah who has given me the strength, ability and patience to complete this Final Year Project as it is today.

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“IT IS BETTER IF YOU ARE APPROXIMATELY RIGHT THAN YOU ARE BEING
PRECISELY WRONG”.

ABSTRACT

The ball and beam control system consists of a small metal ball, a beam, a motor, and an analogue or digital process controller. Two sensors are also required. One is for detecting the position of the ball on the beam and the other is for detecting the angular position of the servo. Both of these sensors are connected to the process controller. The beam is a half meter length with two parallel tensioned wires mounted on it. The two wires are part of the sensor for detecting the position of the ball on the beam and the ball rolls up and down on them. One ended of the beam is connected to a servo motor while the other ended is fixed.

The controller used in this project is PIC 16F877A .The controller compares the desired position of the ball on the beam with its actual position. It then acts through the motor to change the angle of the beam. This causes the ball to roll towards its desired position. As it nears to the desired position, the angle of the beam is reduced so as to bring the ball to a stop at its desired position with a little overshoot as possible.

This report shows the approach used to obtain a valid solution to this problem, as well as the design and development of the controllers were implemented for the system. The Ball and Beam project is intended to be used as a demonstrational device on control systems to attract potential students forward electrical engineering field and control systems design.

Keyword – PWM Servo Motor (180°), Controller PIC 16F877A and Position Sensor (LVDT).

ABSTRAK

Bola dan alang dalam sistem kawalan mengandungi satu bola logam yang kecil, alang, motor, dan analog atau pengawal proses berdigit. Dua pengesan diperlukan di dalam sistem ini. Satu ialah untuk mengesan kedudukan bola dan satu lagi untuk mengesan kedudukan pada sudut servo. Kedua-dua pengesan ini bersambung pada proses pengawal. Panjang alang adalah setengah meter di mana ia bersambung secara selari dengan dua wayar yang dipasang di atasnya. Dua wayar adalah sebahagian penerima untuk mengesan kedudukan bola pada alang.

PIC 16F877A digunakan sebagai pengawal. Pengawal ini akan membandingkan kedudukan bola pada alang dengan kedudukan yang dikehendaki. Kemudian, pengawal ini akan bertindak mengubah sudut pada alang melalui motor. Ini akan menyebabkan bola tersebut bergolek ke arah kedudukan yang dikehendaki. Setelah bola menghampiri kedudukan yang diinginkan, sudut alang dikurangkan supaya dapat membawa bola itu untuk berhenti pada kedudukan yang diinginkan dengan kemungkinan mengalami sedikit lajukan.

Laporan ini menunjukkan pendekatan untuk satu penyelesaian pada sesuatu masalah, serta rekabentuk dan pembangunan alat-alat kawalan telah dilaksanakan untuk sistem itu.

Projek ini sesuai digunakan sebagai suatu alat demonstrasi dalam sistem kawalan bagi menarik bakal pelajar terhadap bidang kejuruteraan elektrik dan rekabentuk sistem kawalan.

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LIST OF SYMBOLS

L	-	Beam length
r	-	Lever arm offset
α	-	Beam angle coordinate
\square	-	Servo gear angle
m	-	Mass of Ball
R	-	Radius of ball
J	-	Ball's moment of inertia ($J = \frac{2}{5}mR^2$)
g	-	Gravitational acceleration $g= 9.8m/s^2$
R	-	Armature resistance
J	-	Moment of inertia of the moving parts
D	-	Damping coefficient due to friction
$\omega(t) = \frac{d\hat{\alpha}(t)}{dt}$	-	Angular velocity
$V_b(t)$	-	Motor back emf $K_b w(t)$
K_b	-	Motor back emf constant
$T_m(t)$	-	Motor torque $K_m i(t)$
$i(t)$	-	Armature current
K_m	-	Motor torque constant

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CHAPTER 1

INTRODUCTION

1.1 Background

Balancing is one of the parts in control system. In order to balance a beam, one can use his hand as support and mind acts as controller to push up or lower down the beam. This will enable the ball to roll back to the centre of the beam. This system is commonly employed as a benchmark control system case study to evaluate advanced control method.

The basic structure of a ball and beam system consists of a beam in horizontal position with one end pivoted on a pole and the other end connected to a level arm that is controlled by a motor. By applying an electrical control signal to the motor, this will enable the beam to be tilted about its edge axis. The control objective is to automatically regulate the position of the ball on the beam by changing the angle of the beam. This is a difficult control task because the ball does not stay in one place on the beam but it moves with acceleration that is proportional to the tilt of the beam. In control technology, the system is considered as open loop unstable because the system output where the ball position increases without limit for a fixed input (beam angle). Feedback control must be applied to keep the ball in the desired position on the beam.

The inverted pendulum is another type of control which is a fast dynamic system. It consists of a pole mounted on a moving cart in such a way that, one end of the pole is pivoted on the cart while the other end is allowed to swing freely. While this would be seen to be a short list, the ball and beam system seems to be a more popular and less structurally complex system to be implemented.

The purpose of the ball and beam control system is to regulate the position of the ball on a potentiometer beam to the desired position via a servo plant. The ball and beam apparatus with the controller measure the positions of the ball on beam by measuring the voltage drop as the ball is travelling along the beam. The beam is composed of a mounted nichrome and bare copper wires that act as a potentiometer in parallel on the beam. After applying a bias voltage at the nichrome wire, the ball position is found to be proportional to the voltage measured at the bare copper wire since nichrome has proportional resistance to its length. The apparatus must be able to place the ball to the same position as the desired position. By attaching the beam to the servo plant, we will be able to control the angle of the beam to move the controlled ball to the desired position. A microcontroller will be used to take in the voltage from the ball and beam sensors (Linear potentiometer) and it will then be converted from analogue signals to digital samples to be used by the controller. Based on the positional error between the measured position and the desired position, the controller will drive the servo plant to move the control beam up and down until the ball lies at the same position as the desired position. In this project, the controller will control the angle of the beam and cause the changing of the ball position.

This project concerns the implementation of a robust control scheme to achieve the desired control objective. A controller is said to be robust if it operates effectively over all possible operating conditions. Since the ball and beam is unstable and contains a number of uncertainties, good result can be expected by implementing the close loop controller.

1.2 Project Aim

This project is about controlling the ball and beam system by implementing close loop control method. The importance of this study as this system is unstable and has numbers of uncertainties. Using close loop control, the uncertainties can be compromised and good results can be achieved. The main objective of this control is to automatically regulate the position of the ball on the beam by changing the angle of the beam. The position of the ball on the beam is measured using linear potentiometer.

1.3 Project Objective

The objective of this thesis is to fabricate the ball and beam system, to design a PIC16F877A controller to control the position of the ball along the track to make it follow a commanded input and to perform real time implementation of controller for verification purposes.

1.4 Problem Statement

Microcontroller is more stable compared to the microprocessor in order to generate the pulse width modulation (PWM) waveform. The microcontroller circuit is also simple and easier to be controlled. Therefore, the microcontroller is cheaper than microprocessor. This system is implementing close loop control method, but this system is unstable and has numbers of uncertainties and lastly is to automatically regulate the position of the ball on the beam by changing the angle of the beam.

1.5 Scope of Project

This project focuses on fabrication of the ball and beam system and the controller design process. The scopes of the project are as below;

i. Fabrication of The Ball and Beam Model

The model is constructed by attaching the right end of beam to the servo motor plant and the left end of the beam is fixed. In order to balance the beam, servo motor as support and mind as controller to push up or lower down the beam.

ii. Designing The Circuit Schematic Diagram

The purpose of the circuit schematic diagram is to act as ADC, controller and PWM signal to the servo motor.

iii. Develop C-compiler Programming

The programming is determined by looking from input, output and flow chart of the system. The purpose of this programming is to keep the ball in the desired position on the beam.

iv. Experiment and Analysis

These controller and model will be analyzed to get their performance. These experiment processes enable identification of the advantages and calibration of using PIC16F877A as controller.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Since the ball and beam system is naturally unstable and nonlinear, it is valuable for research and development purpose. Many researches had been carried out in this field and therefore a number of approaches in balancing the ball and beam system exist. This includes those of Hauser through approximate feedback linearization (Hauser et al, 1992), the method of controlled Lagrangians (Andree et al, 2000; Hamberg, 1999) and the interconnection and damping assignment passivity based control (IDA-PBC).

Besides that, artificial neural network (ANNs) have also been employed to control the ball and beam balancing system in which the system (Jiang et al, 1995) is controlled by a two layer network, developed using error back-propagation (BP) and temporal-difference (TD) learning. The following section reviews some of the work done on the ball and beam system. Andree et al, 2000 have shown the design procedure and results of the implementation of the λ -method on the ball and beam system. They have proven a theorem showing that the family of matching control law of any linear time invariant system contains all linear state feedback control laws. For the ball and beam system, it is observed that the linear control law performs better than the nonlinear control law. A linear dynamic output feedback controller has been designed by Van Acker (Van Acker et al, 2000) for a ball and beam system based on an identified neural state space model. This is done by applying dynamic back-propagation, constrained by q NL internal or I/O stability conditions representation of the closed-loop system.

The q NL theory enables a top-down linear or neural controller design for general non-linear systems, based on identified neural state space model. (Gordillo et al, 2002) have done a research on the transient performance problem on ball and beam system. They

propose an asymptotically stability controller that ensure that, for all a well defined set of initial conditions, the ball remains on the bar during the transient. The controller is a nonlinear static state feedback that is derived using the interconnection and damping assignment energy shaping controller design methodology. (Qiang Wang et al, 1998) have presented an evolutionary controller design method for a ball and beam system. The method consists of population of feed forward neural network controllers that evolve towards an optimal controller through the use of a genetic algorithm. In the genetic algorithm, each neural network is represented by an individual “chromosome”. The chromosome consists of an array of connection genes which represents a single possible connection of the network. The optimal controller is then applied to several different initial positions from which it has to balance the system. In 1996, Prof. Lotfi Zadeh (Zadeh, 1996) issued a more complex problem involving dynamic motion planning in which the beam is assumed to be covered with a strip of fuzzy material. The fuzziness of the beam’s surface is intended to preclude the possibility of setting up the differential equations governing the ball’s motion on the beam. This makes it very difficult to use classical control techniques to derive a way of stabilizing the ball within a prescribed interval. However, Paul H. Eaton (Eaton et al, 1998) used the approach to train neuro-controller on a model of the system off-line and then deploy them with fixed weights for testing on actual system on-line. Their neuro-controller uses a form of approximate dynamic programming called an adaptive critic design that uses Dual Heuristic Programming (DHP), an upper-level design.

2.2 Close Loop

The ultimate goal of a control system designer is to build a system that will work in real environment. Since the real environment of ball and beam control system may change with time (as components age or their parameters vary with temperature or other environmental conditions) or operating conditions may vary as load changes and presents of disturbances, the control system must be able to withstand these variations. In the case where the environment does not change, the issue of model uncertainty becomes significant. A mathematical representation of a system often involves simplifying and sometimes wishful assumptions. Since the ball and beam control system is typically designed using much simplified model (ignore nonlinearities, neglect present of

perturbations and dynamic structure), it may not work properly on the real plant in real environment. The particular property of a control system must possess to operate properly in realistic situations is called close loop.

2.3 Close Loop Controller

If we design a controller that will stabilize the system in specified range, we can say the system has close loop stability. In addition, if performance specifications such as steady state tracking, disturbance rejection and speed of response are required, we say the system possesses close loop performance. The problem of designing controllers that satisfy close loop stability and performance requirements is called close loop controller. This problem was investigated intensely during the 1980s (Stefani et al, 2002) and still under investigation by many researchers following a variety of approaches.

2.4 Feedback Control System Configuration

Consider the structure shown in figure 2.1.

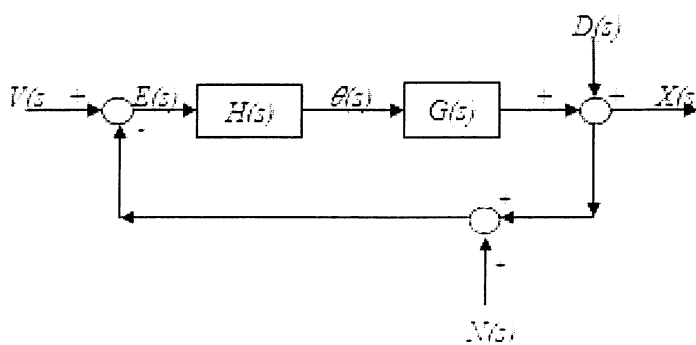


Figure 2.1: Feedback control system configuration

A close loop designed control system must track reference inputs with small error and reject disturbance and noise inputs. The contribution of general disturbances to the output must be small.

In this case, the total output of the closed-loop system is

$$X(s) = \frac{G(s)H(s)}{1 + G(s)H(s)} V(s) + \frac{1}{1 + G(s)H(s)} D(s) - \frac{G(s)H(s)}{1 + G(s)H(s)} N(s)$$

If we define the tracking error as $e=v-x$, we get

$$E(s) = \frac{G(s)H(s)}{1 + G(s)H(s)} V(s) - \frac{1}{1 + G(s)H(s)} D(s) + \frac{G(s)H(s)}{1 + G(s)H(s)} N(s)$$

Then, the actuator (servo motor) output or plant (ball and beam) input, will be

$$\theta(s) = \frac{H(s)}{1 + G(s)H(s)} [V(s) - D(s) - N(s)]$$

Note that, several quantities appear frequently in above relationship. They are

$$S(s) = \frac{1}{1 + G(s)H(s)}$$

$$T(s) = \frac{G(s)H(s)}{1 + G(s)H(s)}$$

As a result,

$$S(s) + T(s) = 1$$

Using earlier definitions, we can write

$$X(s) = S(s)D(s) + T(s)[V(s) - N(s)]$$

$$E(s) = S(s)[V(s) - D(s)] + T(s)N(s)$$

$$\theta(s) = H(s)S(s)[V(s) - D(s) - N(s)]$$

Now, from these equations we can make several conclusions:

- Good disturbance rejection: Sensitivity function must be kept small to minimize the effect of disturbances.
- Good command following: Sensitivity function must be kept small to keep tracking small error.
- Noise attenuation: Complimentary sensitivity function must be small to reduce the effect of measurement noise on the output and errors.

From the conclusions that we have made from previous relationship, we can say that good command following and disturbance rejection require small sensitivity while noise attenuation requires small in complimentary sensitivity. It was stated earlier that these two transfer function add up to unity. So, we cannot reduce both to zero simultaneously. However, in practice, command inputs and disturbances are low frequency signals as they vary slowly with time while measurement noise is a high frequency signal. Therefore, we can meet both objectives by keeping sensitivity function in low frequency range and complimentary sensitivity function in high frequency range. Bode (Stefani et al, 2002) has shown that for a stable system, the transition from low to high frequency range must not be smooth, for example $-20\text{dB} / \text{decade}$ and not to exceed $-40\text{dB} / \text{decade}$. If there is no disturbance ($d = 0$), a perfect feed forward controller could be obtained just by using the controller. However, because of the presence of signal uncertainty, model uncertainty and unstable plants, it is usually necessary to use feedback.

2.5 Feedback Properties

Sensitivity and disturbance rejection are the two properties that a feedback system have which cannot be obtained by using an open loop system. Sensitivity refers to the capability of the feedback to reduce the sensitivity of the closed-loop system with respect to uncertainties or variations in elements located in the forward path of the system. Meanwhile, disturbance rejection refers to the fact that feedback can eliminate or reduce the effects of unwanted disturbance occurring within the feedback loop. The open-loop system can also eliminate certain disturbances but it requires full knowledge of the disturbance which is not always available. Since the objective is to achieve close loop system, feedback control is necessary.