Modelling and Control of Ball and Beam System using PID Controller

B.TECH PROJECT

Submitted in partial fulfilment of
The requirements for the degree of

BACHELOR OF TECHNOLOGY

IN

INSTRUMENTATION AND CONTROL

Aditya Chandrakant Gole - 111909037
Anvay Abhay Parwekar - 111909038

Department of Instrumentation and Control
College of Engineering, Pune-411005

(2021-22)

CERTIFICATE

DEPARTMENT OF INSTRUMENTATION AND CONTROL

COLLEGE OF ENGINEERING, PUNE
(An Autonomous Institute of Govt. of Maharashtra)

Certified that the project title **Modelling and Control of Ball and Beam System using PID Controller**. Submitted by **Aditya Chandrakant Gole & Anvay Abhay Parwekar** having MIS no:111909037 and MIS no:111909038 reapectively in the partial fulfillment of the requirements for the award of **Bachelor of Technology (Instrumentation and Control)** degree of College Of Engineering Pune is a record of student's own work carried out by them under my supervision and guidance.

Project Guide
(Dr. A. S. Deshpande)

Head
(Dr. D. N. Sonawane)
Dept. of Instrumentation and Control

Date: May 6^{th}2022

Date: May 6^{th}2022

Contents

List of Figures

List of Tables

List of Symbols

Symbols used are shown in Table

Name	Description	Unit
g	Acceleration due to gravity	m/s^2
m_b	Mass of the ball	kg
R_b	Radius of the ball	m
d	Lever arm offset	m
L_B	Length of beam	m
J_b	Moment of Inertia of Ball	kgm^2
r_b	Ball's Position coordinate	m
$theta_1$	Beam angle coordinate	rad
$theta_2$	Servo gear angle	rad

Table 1: Symbols used

Abstract

Ball and beam system is highly non linear system. The study of such non linear system makes it easy for us to analyze highly complex systems like Missiles and Aeroplanes. Here considering the beam angle of servo motor we have designed controllers to control the ball position. Lagrange approach is used to find the ball position of the system. It is based on energy balance technique and the analysis is carried out based on open and closed loop transfer function. The nonlinear characteristic of the second order system is regulated by using PID controller. The controller controls the ball position by adjusting the beam using according to its position over the beam. The parameters of the PID are tuned using PID tuning Algorithm. We have implemented three control methods PI, PD and PID to show which controller is best for control of such highly non-linear systems.

Chapter 1

Introduction

The ball and beam system is one of the most basic and crucial reference point systems. The ball and beam system is a fundamental system. Adaptive dynamic surface controller is used to achieve the ball positioning. Most contemporary and current methods have been used to balance the ball and beam system.

In this paper, the sensor finds the ball role along the beam and also finds position and locates one side of the beam. An actuator acquires the beam at a desired angle, by sending a torque at the end of the beam. The ball position is balanced by a controller by changing the angle of servo motor.

Due to the complexity and the non linearity of the administrative dynamics, some research workers used non-model based control strategies such as Fuzzy Logic, Neural Network and PID to command the ball position and beam angle. The non-model based approach does not require mathematical operation to acquire the dynamic equations and to employ linearization. However, these approaches are mainly knowledge based and cannot guarantee the stability of the system.

To support our claim we have modeled an Open Loop System as well as Closed loop System. Open-loop system, also reference to as without feedback system, is a type of continuous control system in which the output has no power or effect on the control action of the input signal. The system has no control on the output. The deviation from required output can be very large as it has no information about the actual output of the system.Another drawback of open-loop systems is that they are poorly equipped to handle disturbances or changes in the conditions which may decrease it's perform to complete the desired task.

The Closed Loop Control System is a system where the actual behaviour of the system is sensed and then feed back to the controller and mixed with the citation or desired state of the system to modify the system to its desired state. The goal of the control system is to estimate solutions for the proper corrective action to the system so that it can hold the set point (reference) and not fluctuate around it.

Chapter 2

System Description & modeling

In order to acquire a ball and beam system dynamic equation, Lagrange approach is used to find the ball position of the system. It is based on the energy balance of the system. The Lagrange approach is used to acquire the motion equations for the ball and beam system. The ball and beam system is the greatest model based research work(Fig 2.1)

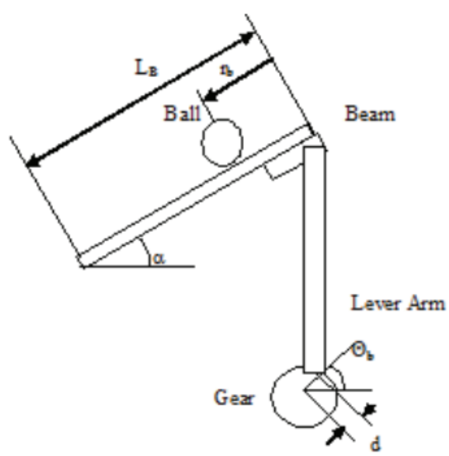

Figure 2.1: Schematic diagram of system

2.1 Mathematical modeling

Modeling of a system is done considering free body diagram of a system.

Symbols used are shown in Table (2.1).

Description	Symbol	Value
Acceleration due to gravity	g	9.81 m/s^2
Mass of the ball	m_b	0.11 kg
Radius of the ball	R_b	0.015 m
Lever arm offset	d	0.003 m
length of beam	L_B	1.0 m
Ball's moment of inertia	J_b	$9.99 * 10^{-6}$ kgm^2

Table 2.1: Symbols used in Ball Beam model

$$K = \frac{1}{2}(m_B r^1 + J_B(\frac{r'}{R_b})^2 + (J_B + m_B r'^2)\alpha'^2 + J_b \alpha'^2) \tag{2.1}$$

$$P = \frac{1}{2} m_b g \sin\alpha + m_{\mathbf{B}} g r \sin\alpha \tag{2.2}$$

where K is the Kinetic Energy of ball. P is the potential energy of the ball.

2.2 Lagrangian Approach

The Lagrange function is the dissimilarity between kinetic energy and potential energy, which is defined by L equation,

$$L = K - P \tag{2.3}$$

$$0 = (\frac{J}{R_b^2} + m_b)r_b'' + m_b g \mathrm{sin}\alpha - m_b r_b \alpha'^2 \tag{2.4}$$

$$\frac{d}{dt}(\frac{\partial L}{\partial q'}) - \frac{\partial L}{\partial q} = T \tag{2.5}$$

$$(\frac{J}{R_b^2} + m_b)r_b'' = -m_b g \alpha \tag{2.6}$$

Here T is the torque produced by the motor.

$$\alpha = \frac{d}{L}\theta \tag{2.7}$$

$$(\frac{J}{R_b^2} + m_b)r'' = -m_b g \frac{d}{L_B}(\theta) \tag{2.8}$$

By taking the Laplace transform of the previous equation, now we get the following equation

$$(\frac{J}{R_b^2} + m_b)R(s)s^2 = -m_b g \frac{d}{L_B}(\theta(s)) \tag{2.9}$$

Rearranging the equation we can find the transfer function from the gear angle to the ball position.

$$P(S) = -m_b g \frac{d}{L_B} (\frac{J}{R_b^2} + m_b)/s^2 \tag{2.10}$$

Chapter 3

Analysis

The analysis of the transfer function(eq. 2.10) is carried by modelling the system in MATLAB Simulink. Open loop and Closed loop control along with P, PI, PD, PID controllers are used in order to make the system stable.

3.1 Open Loop Control

An open loop system is a system that does not have any feedback. The output may or may not be according to the desired output. As the feedback is absent so an open loop system is generally unstable.
The system is represented in the fig 3.1.

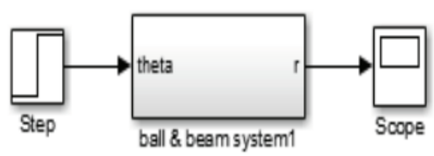

Figure 3.1: Diagram of open loop system simulink model

The subsystem block that takes input θ and output as r is also modelled in MATLAB/Simulink as it's block diagram is shown in fig. 3.2.

3.2 Closed Loop Control

The Closed Loop Control System is a system where the actual behaviour of the system is sensed and then feed back to the controller and mixed with the citation or desired state of the system to modify the system to its desired state. The goal

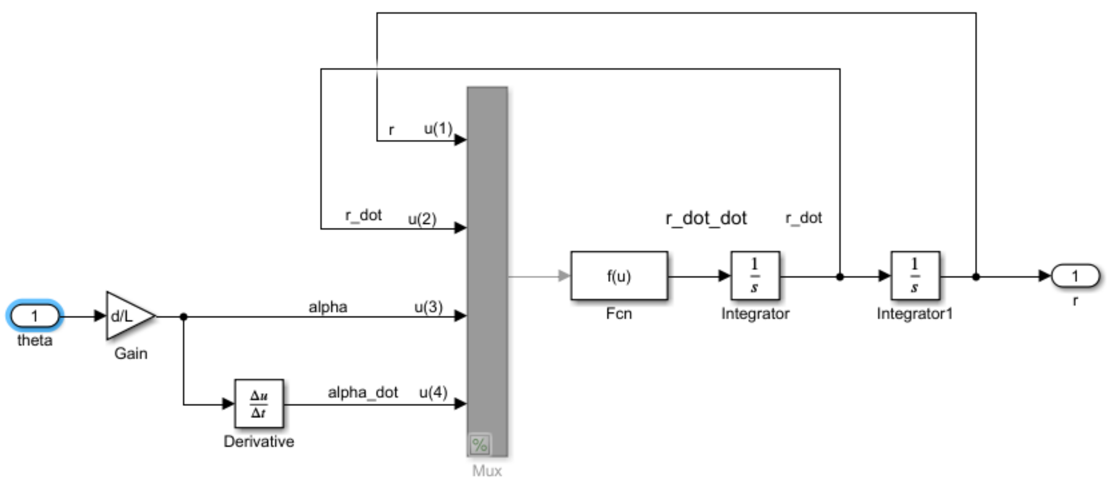

Figure 3.2: Subsystem

of the control system is to estimate solutions for the proper corrective action to the system so that it can hold the set point (reference) and not fluctuate around it.

In order to control the system a controller needs to be designed. A PID controller will be needed to be designed. The general equation of PID controller is given below :

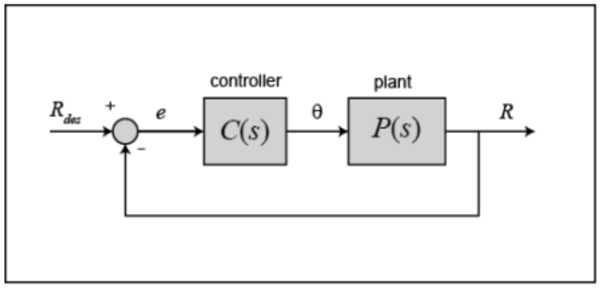

Figure 3.3: Closed Loop control for ball beam setup

$$K_p + \frac{K_i}{s} + (K_d)s$$

PID controller is tuned with the help of PID auto tuner which is present in MATLAB/Simulink.

3.2.1 PI Controller

The PI controller is used to regulate the transient response and in our case PI controller reduces the open loop response from infinity to a oscillatory response. The graphical representation will be provided in the results section. The PI controller along with P, I parameters is shown in fig 3.4.

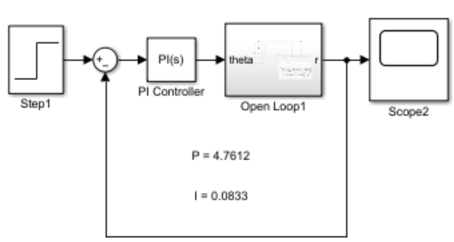

Figure 3.4: PI Controller

3.2.2 PD Controller

The PD controller helps to eliminate the steady state error and also helps to keep the transient response of system in check. It does not allow the response to jump off to infinity.The PD controller also reduces the overshoot of the system to a great extent. The overshoot in our case is 12%
The Simulink block diagram of PD controller with tuned P and D parameters is shown in fig. 3.5

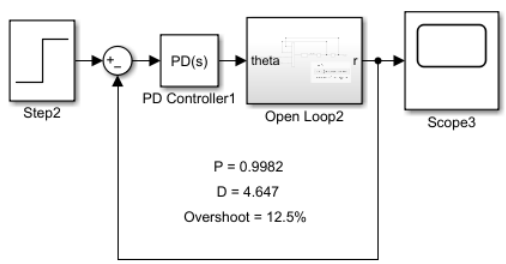

Figure 3.5: PI Controller

3.2.3 PID Controller

The PD controller did reduce the overshoot and steady state error but we want the overshoot to be less than or equal to 10%. So PID control is implemented and it is tuned with Simulink PID tuner block.(Fig. 3.6)

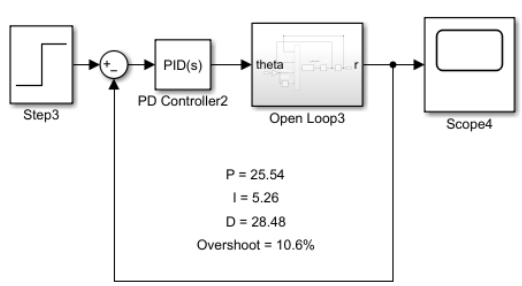

Figure 3.6: PID Controller

Chapter 4

Result

4.1 Simulation Results

This section highlights validation of the proposed control method, which is done using MATLAB/Simulink software. The response of the system is plotted and the results are analyzed.

4.1.1 Open loop response

We can see that the response shoots off to infinity.(fig. 4.1)
This means that of we place a ball on the beam then the ball would simply roll off as there isn't any feedback about the current position of the ball. To prevent this from happening we will implement advanced control methods like P, PI, PID to meet desired response.

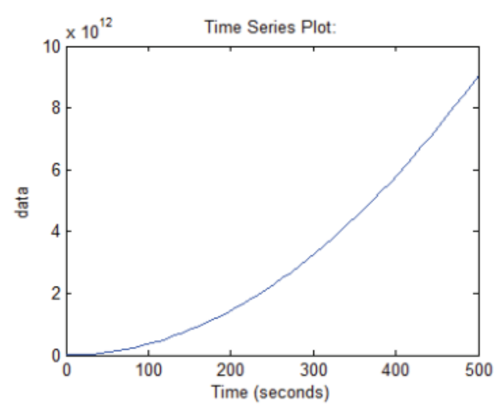

Figure 4.1: Open loop response

4.1.2 PI Controller response

The PI controller is first step toward the control of the system.It narrows down the response of open loop system from infinity to oscillatory response.(fig. 4.2).
If we place the ball on the beam them the beam will not be stable rather it will oscillate and eventually ball will fall off.

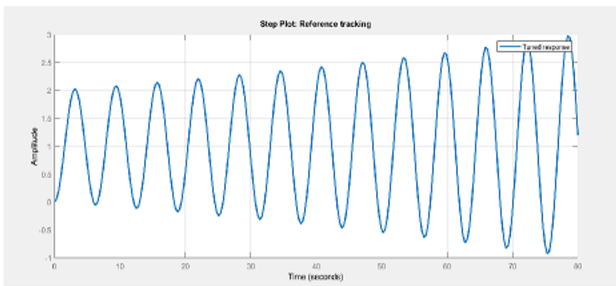

Figure 4.2: Response of PI controller

4.1.3 PD Controller response

The PD controller will reduce the oscillatory response of the system and also reduce the steady state response to a great extent. This means that if we place the ball anywhere on the system the system will be able to control the ball on the beam but the beam will have a large overshoot and also the the beam will not be exactly parallel to the ground, the beam will be slightly tilted.

4.1.4 PID Controller response

Finally, to control the system fully we will design PID control. This will reduce the steady error more than PD controller did. Also the overshoot will be reduced.

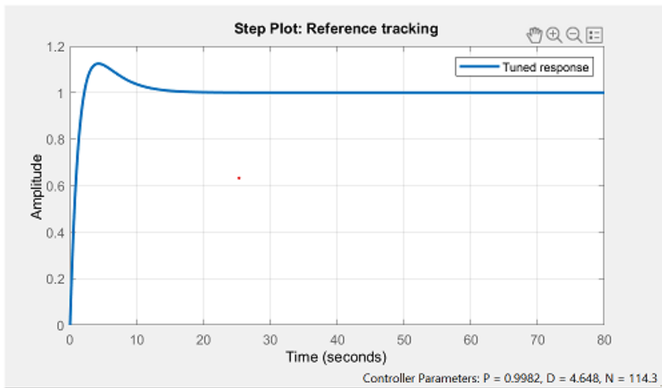

Figure 4.3: Response of PD controller

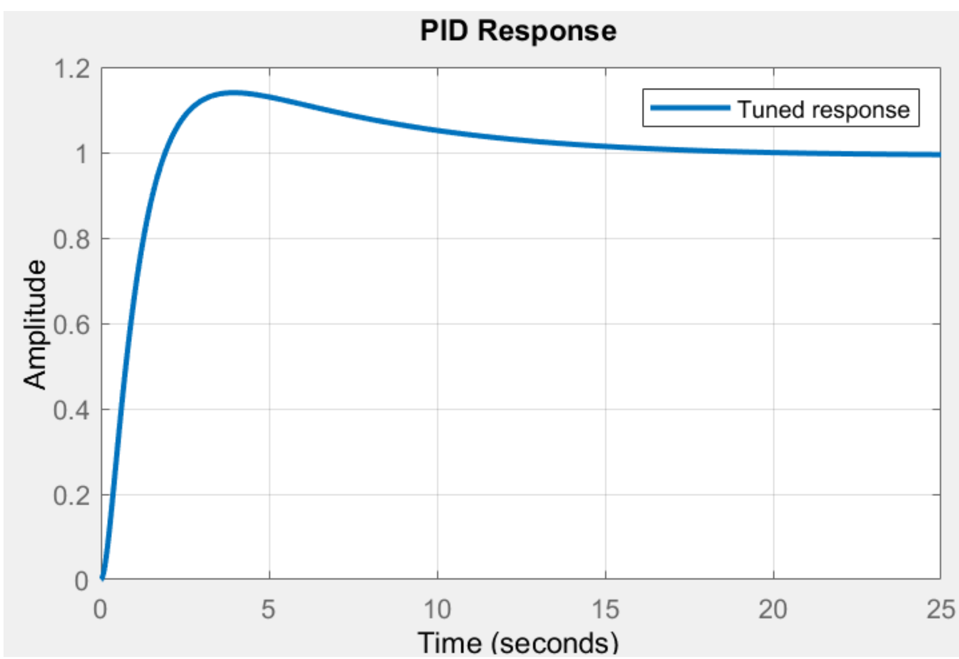

Figure 4.4: Response of PID controller

Chapter 5

Conclusion

The PID based control is implemented for the ball and beam system. The response of PI, PD and PID is calculated and compared with each other. Based on the comparison it is finally decided that PID controller is best fit for control purpose. PID controller not only reduced the steady state error but it also reduced the overshoot and the settling time of the entire ball beam system. To achieve this we took the help of MATLAB/Simulink and modelled our system in the Simulink. To tune the PID controller we used the PID auto tuner which was present in the simulink blocks. The PID controller has proved to be advantageous as it removes the effect of chattering and stabilized the system.

References

[1] P. V. M. Maalini, G. Prabhakar, and S. Selvaperumal, “Modelling and control of ball and beam system using pid controller,” in *2016 International Conference on Advanced Communication Control and Computing Technologies (ICACCCT)*, pp. 322–326, 2016.

[2] K. Prasad and Y. Hote, “Optimal pid controller for ball and beam system,” in *International Conference on Recent Advances and Innovations in Engineering (ICRAIE-2014)*, pp. 1–5, 2014.

[3] S. Latif, E. Muhammad, and U. Naeem, “Implementation of ball and beam system using classical and advanced control techniques,” in *2019 International Conference on Applied and Engineering Mathematics (ICAEM)*, pp. 74–79, 2019.

[4] P. Jain and M. J. Nigam, “Real time control of ball and beam system with model reference adaptive control strategy using mit rule,” in *2013 IEEE International Conference on Computational Intelligence and Computing Research*, pp. 1–4, 2013.

[5] P. Rapp, O. Sawodny, and C. Tarín, “Stabilization of the ball and beam system by dynamic output feedback using incremental measurements,” in *2013 European Control Conference (ECC)*, pp. 288–294, 2013.

[6] B. Ahmad and I. Hussain, “Design and hardware implementation of ball amp; beam setup,” in *2017 Fifth International Conference on Aerospace Science Engineering (ICASE)*, pp. 1–6, 2017.