Modelling and Control of Ball and Beam System using PID Controller

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***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.**

***Index Terms*—PI control, PD control, PID control**

I. 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. Fig. 1. shows the schematic of ball and beam system.

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

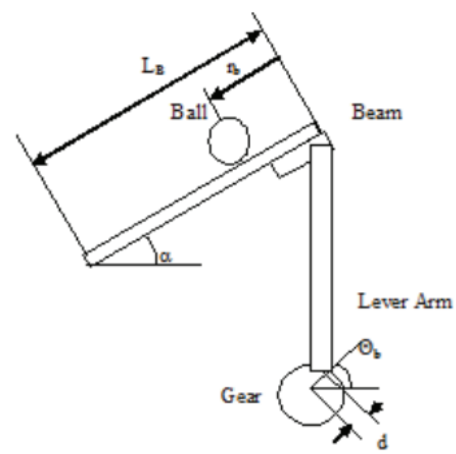

Fig. 1. Schematic of Ball and beam System

- m_b = Mass of ball
- R_b = Radius of ball
- d = Lever arm offset
- g = Gravitational acceleration
- L_B = Length of Beam
- J_b = Moment of Inertia of ball
- r_b = Ball position coordinate
- θ_1 = Beam angle coordinate
- θ_2 = Servo gear angle

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.

II. Mathematical Modelling

We need to find the dynamic equations of motion and for that we use lagrangian approach. The mechanism of the ball and beam system contains two DOFs.The mechanism of the ball and beam system contains two DOFs. Initially the Euler-Lagrange equation is used to define the kinetic energy and potential energy for the system.

A. Equations

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

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

B. Lagrangian Approach

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

$$L = K - P \tag{3}$$

$$0 = (\frac{J}{R_b^2} + m_b) r_b'' + m_b g \text{sin}\alpha - m_b r_b \alpha'^2 \tag{4}$$

$$\frac{d}{dt}(\frac{\partial L}{\partial q'}) - \frac{\partial L}{\partial q} = T \tag{5}$$

$$(\frac{J}{R_b^2} + m_b) r_b'' = -m_b g \alpha \tag{6}$$

Here T is the torque produced by the motor.

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

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

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

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

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

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

C. Simulation Result

Here we are considering both open and closed loop syste Then we apply PID controller to the closed loop system a tune it.

1) Open loop system: Simulink Model of open loop system for ball and beam is shown in the figure. Modelling is done using Matlab simulink.

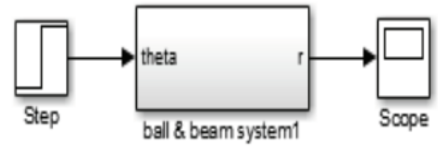

Fig. 2. Diagram of open loop system simulink model

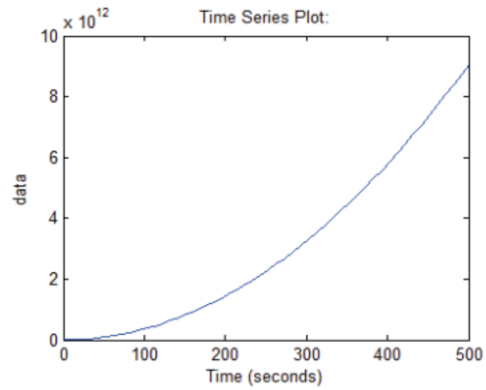

Fig. 3. Output of open loop system

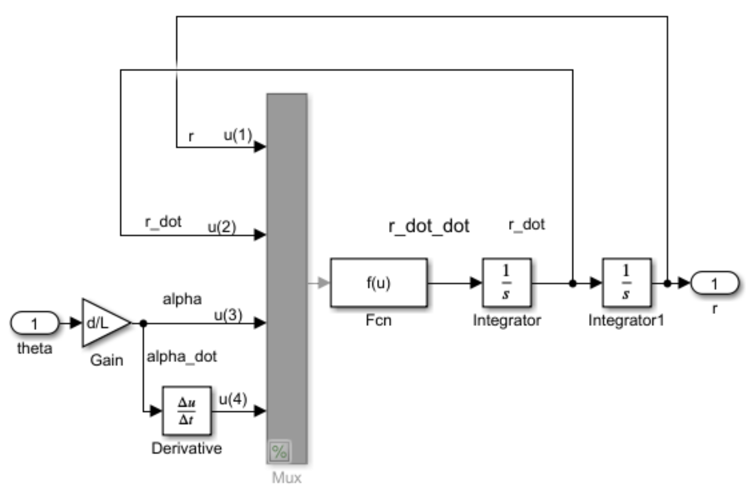

Fig. 4. Subsystem

2) Close loop system: The response of open loop system(Fig. 3) goes to infinity so provide a feedback and an closed loop system is formed.

3) PI controller: To improve transient response PI controller is designed which limits the output from going to infinity. The circuit diagram for PI controller is shown in Fig. 5.

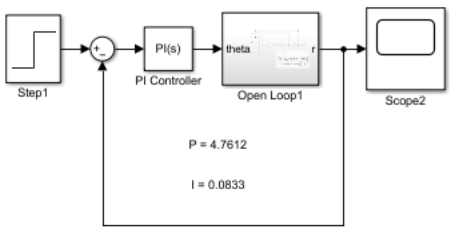

Fig. 5. PI CONTROLLER

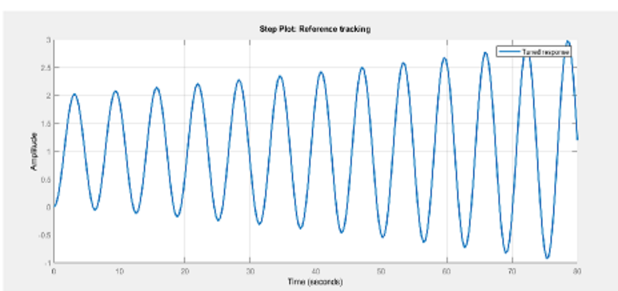

Fig. 6. PI Controller response

4) PD controller: To keep in check the oscillatory response(Fig. 6) PD controller is designed so that a steady transient response is obtained.

5) PID controller: The PD controller does reduce oscillations but the steady state error and overshoot still are not reduced. So to reduce the SSE and %Overshoot PID controller is used.(Fig. 9). The response of the PID controller

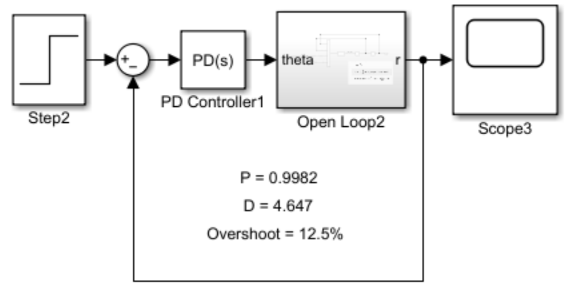

Fig. 7. PD Controller

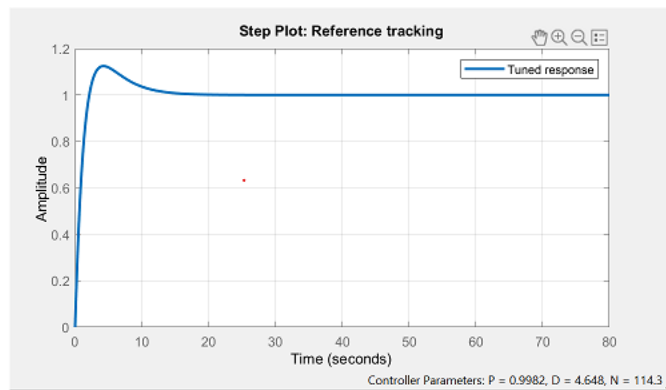

Fig. 8. PD Controller response

is shown in Fig. 10

D. Conclusion and future work

Thus the project is to model and control the ball and beam system by considering the beam angle of servo motor and designing controllers to control the ball position. Then position of ball is found using Lagrange method.Then based on the transfer function and state space model open loop and closed loop system are designed.

As the system is non linear it's behaviour is controlled by using PID controller. The PID controller is tuned using PID tuning Algorithm. In order to completely analyze the system P(Proportional), PI(Proportional-Integrator), PD(Proportional Derivative) and PID(Proportional Integrator Derivative) all the

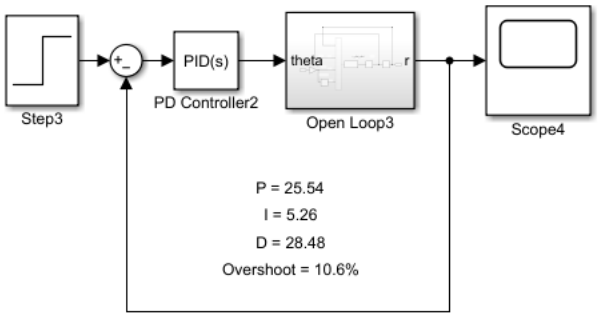

Fig. 9. PID Controller

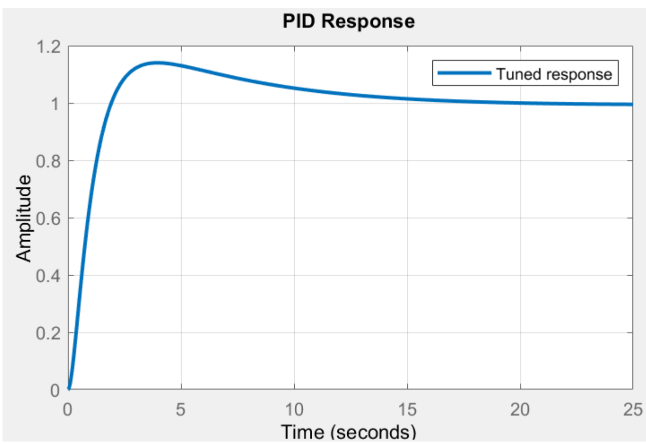

Fig. 10. PID Controller response

controllers are used and the response of each controller is separately analyzed.

Further the closed loop performance will be optimized using Fuzzy logic and hardware implementation will be done. Then the comparison will be made between the hardware and software results.

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