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Modelling and Control of Ball and Beam System using PID Controller

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***Abstract*: The ball and beam is a basic reference point system with high nonlinearity and unstable system in its dynamics. Many simple and present day control methods have been used to balance the ball and beam system. The goal of this project is to model and control the ball and beam system. Here considering the beam angle of servo motor and designing controllers to control the ball position. Lagrange approach is used to find the ball position of the system. It is based on energy balance of the system. Based on the transfer function and state space model, open loop system and closed loop system are designed. The system is designed by using two Degrees-of-Freedom. The nonlinear characteristic of the second order system is regulated by using PID controller. The controller controls the ball position in moving the beam using the motor and beaten the disturbances. The parameters of the PID are tuned using PID tuning Algorithm. In order to analyse the accomplishment of PID to learn the effect of simplifying expectation, two control methods are designed and implemented using Proportional Derivative Integral (PID) as non-model based control method, Proportional Derivative and Proportional integral combination of model based and non-model based control methods.**

Keywords- PI control; PD control; PID control.

I.INTRODUCTION

The ball and beam system is one of the most prominent and crucial reference point systems. The ball and beam system is an ambiguous 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 [1]-[2]. The design of a fuzzy logic controller for the ball and beam system using a modified Ant Colony Optimization (ACO) method is used to optimize the type of membership functions, the membership function parameters and the fuzzy rules [3]. The hierarchical fair competition-based genetic algorithm (HFCGA) is to introduce the fuzzy cascade controller scheme which consists of the outer controller and the inner controller in a cascaded architecture [4]. The tracking and almost disturbance decoupling problem of nonlinear AMIRA's ball and beam system based on the feedback linearization approach and fuzzy logic control [5]. The State Dependent Riccati Equation (SDRE) technique for a ball and beam system, which is inherently nonlinear and unstable system [6]. 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.

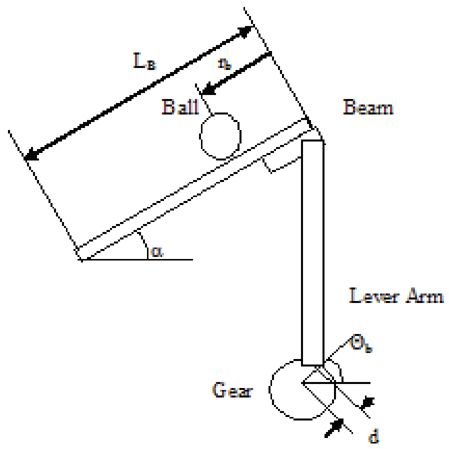

Figure1.1 Schematic of the Ball and Beam System

- (mb) mass of the ball
- (Rb) radius of the ball
- (d) lever arm offset
- (g) gravitational acceleration
- (LB) length of the beam
- (Jb) ball's moment of inertia
- (rb) ball position coordinate
- (θ_1) beam angle coordinate
- (θ_2) servo gear angle

The ball position is balanced by the controller in moving the beam using the motor and also beaten the disruption. The ball position can be changed without ceiling for beam angle fixed input. This property has made system. A convenient device is used to test contrasting control approaches. The ball and beam system contain two Degrees-of-Freedom (DOFs). The ball is simulated to have rotary movement of inertia friction during moving on the beam. However, some of the properties were erased in the most research work concerning the balland beam mechanism in order to simplify the dynamic equation of the system. The ball and beam system is popular and valuable laboratory

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models for teaching control systems. However, the motion of the ball and the motor angle communicate in the real system. The ball has a poor value during the slow movement of the angular velocity of the beam. Therefore, this specification was neglected in modeling of the ball and beam system.

However, when the ball is away from the familiar point, the beam should rotate with noticeable velocity in association to the alternative parameters. In addition, the carioles acceleration term straightly relates to the beam angle.

Due to the complexity and the nonlinearity 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, which May aspect challenge to control the unstable ball and beam system.

The current research has focus on three main issues: comparing the performances of model based and non-model based control strategies, learning the coupling effect in the dynamic equations and designing an optimal control approach seeing the system dynamic requirements (i.e. the moment of inertia of the beam and ball, and beam angular velocity).

Model-Based Design (MBD) is a mathematical and visual method of addressing problems it combines with creating complex control, communication systems and signal processing. It is used in different movement controls, aerospace, industrial equipment and automotive applications. Model-based design is a technique applied in designing embedded software.

Then an 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. In other words, in an open-loop control system the output is neither calculated nor “fed back” for comparison with the input. Therefore, an open-loop system is predictable to firmly follow its input command or set point indifferent of the final result. In an open-loop system, it has no information of the output condition so it cannot rectify any errors it could make when the present value drifts, even if this results in large deviations from the present value. 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.

Closed loop control systems are those that supply the feedback of the actual state of the system and compare it to the desired state of the system in order to change the system. It supplies the desired output. 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

In order to acquire ball and beam system dynamic equation, Lagrange approach is used to find the ball position of the system. It is based on 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.

The mechanism of the ball and beam system contains two DOFs. Initially the Euler-Lagrange equation is used to define the kinetic energy (1) and potential energy (2) for the system.

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

$$P = \frac{1}{2}m_b g\sin\alpha + m_{\mathbf{B}} gr\sin\alpha \quad (2)$$

The parameters m_B is ball mass, m_b is beam mass, J is the beam moment of inertia and R is radius of the ball, and also g is the gravity acceleration and l is the length of the beam; variable is the linear movement of the ball and beam and another variable α is beam angle.

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

$$L = K - P \quad (3)$$

The dynamic equation (4) representing the variation effect of system variable. Equation (4), equation (5) and (6) show the dynamic equation for two DOF’s of the ball and beam system.

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

$$\frac{d}{dt}(\frac{\partial L}{\partial q'}) - \frac{\partial L}{\partial q} = Q \quad (5)$$

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

where τ is the torque produced by the motor applied on the end of the beam.

$$\alpha = \frac{d}{L}\theta \quad (7)$$

$$(\frac{J}{R_b{}^2} + m_b)r'' = -m_b g\frac{d}{L_B}(\theta) \quad (8)$$

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

$$\left(\frac{J}{R_b^{2}}+m_b\right)R(s)s^{2} = -m_b g\frac{d}{L_B}(\theta(s)) \tag{9}$$

Rearranging the equation (9), we can find the transfer function from the gear angle $(\theta(s))$to the ball position$(R(s))$,

$$P(S) = -m_b g\frac{d}{L_B}\left(\frac{J}{R_b^{2}}+m_b\right)/s^{2} \tag{10}$$

This is the final open loop system function of ball and beam system. The reference point ball and beam system set up consists of a long. A servo motor is attached to the other end of the beam. The ball is moving placed on the long beam.

III.SIMULATION RESULT

In this project, open loop system and closed loop system are present. In the open loop system, the output response is not controllable. After that, the closed loop system of PID controller is modelled then tuning the PID controller for getting the controlled output response.

A. OPEN LOOP SYSTEM

This diagram represents full view of the Simulink model of open loop system for ball and beam. Ball and Beam is modelled by calculating mathematical modelling which is implemented by MATLAB Simulink. In the Ball and Beam Open Loop System, the step input value is 5 and the system has Lagrange function.

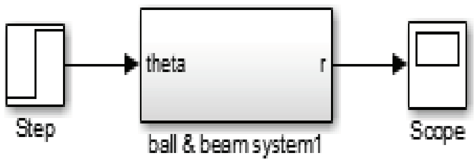

Figure 3.1 Simulink Diagram of Open Loop System

This is the subsystem of Ball and Beam, It consist of Multiplexer, Integrator and derivative function. Multiplexer add multiple inputs and provide single output. The ball and beam Lagrange function have the equation of transfer function.

B. CLOSED LOOP SYSTEM

This diagram represents full view of the Simulink model of closed loop system for Ball and Beam.

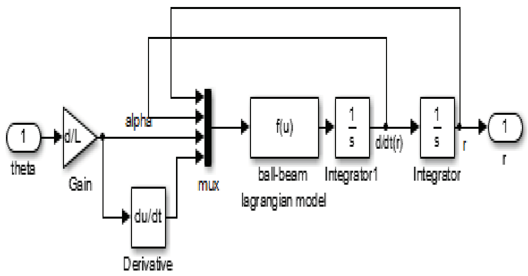

Figure 3.2 Simulink of Sub System

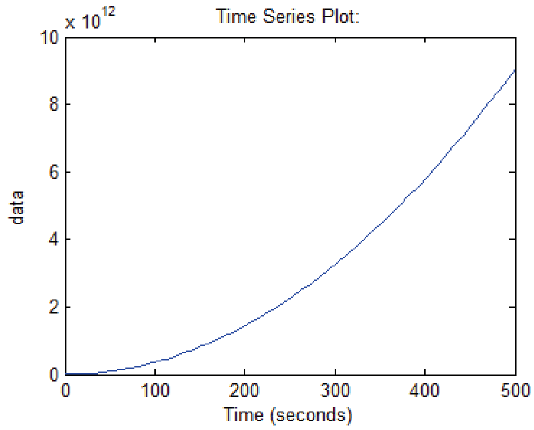

Figure 3.3 Response of open loop system

Ball and Beam is modelled by calculating mathematical modelling which is implemented by matlab Simulink. The step input value 5 is given to the summer then to get the output of transfer function. Summer send to the proportional Integral controller which is to eliminate steady state error but yield the poor transient response. The transfer function has the Lagrange equation. The proportional controller response does not reach the target for that reason we go to the PI controller.

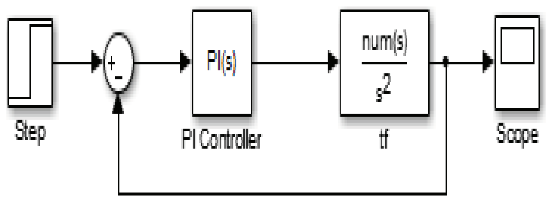

Figure 3.4 Closed Loop Systems with PI Controller

This diagram represents full view of the Simulink model of closed loop system for Ball and Beam. Ball and Beam is modelled by calculating mathematical modelling which is implemented by matlab Simulink. The step input value 5 is given to the summer then to get the output of transfer function. Summer send to the proportional Derivative controller which is provide the good system stability and transient response. It reduces the overshoot.

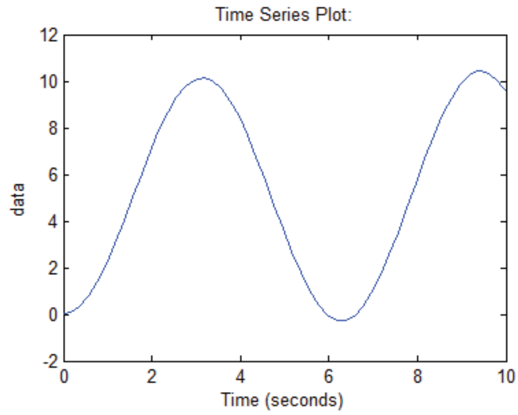

Figure 3.5 Responses with PI Controller

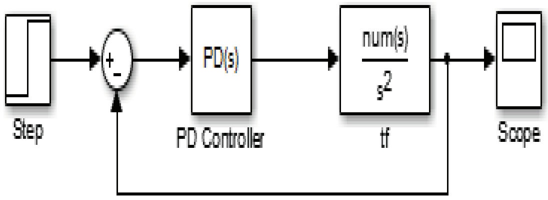

Figure 3.6 Closed Loop Systems with PD Controller

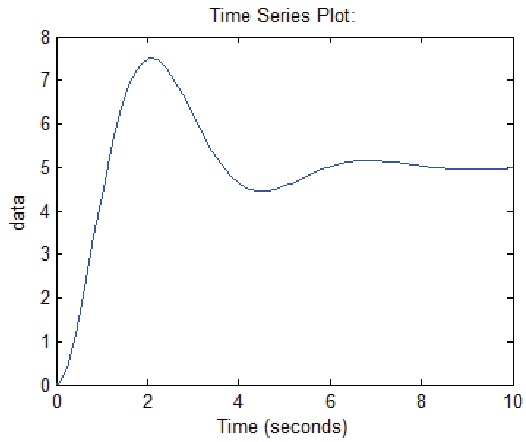

Figure 3.7 Responses with PD Controller

This diagram represents full view of the Simulink model of closed loop system for Ball and Beam. Ball and Beam is modelled by calculating mathematical modelling which is implemented by matlab Simulink.

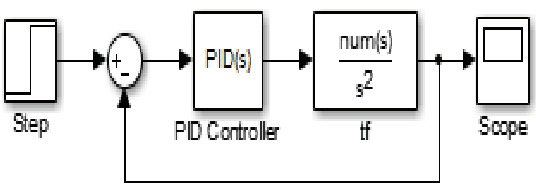

Figure 3.8 Closed Loop Systems with PID Controller

The step input value 5 is given to the summer then to get the output of transfer function. Summer send to the proportional Derivative controller which is provide the good system stability and transient response. It reduces the overshoot.

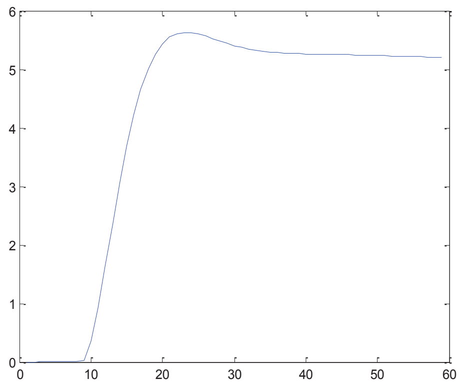

Figure 3.9 Responses with PID Controller

This diagram represents full view of the Simulink model of closed loop system for Ball and Beam. Ball and Beam is modelled by calculating mathematical modelling which is implemented by matlab Simulink. The step input value 5 is given to the summer then to get the output of transfer function. Summer send to the PID controller which is provide the good system stability and transient response. It decreases the overshoot. The transfer function output and disturbance signal added and send to the scope.

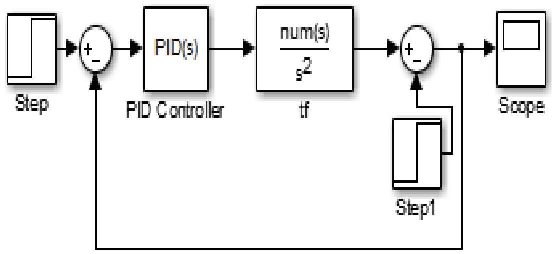

Figure 3.10 PID Controller with Disturbance

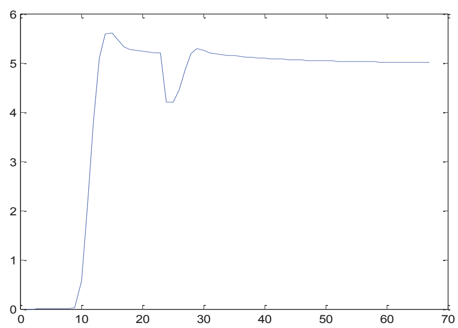

Figure 3.11 Regulator response of PID Controller

IV.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 find the ball position of the system using Lagrange method. Based on the transfer function and state space model, open loop system and closed loop system are designed. The nonlinear behaviour of the second order system is controlled using PID controller. The parameters of the PID are tuned using PID tuning Algorithm. In order to analyse the accomplishment of PID and learn the effect of simplifying expectation. Two control methods are designed and implemented using Proportional Derivative Integral (PID) as non-model based control method, Proportional Derivative and Proportional integral combination of model based and non-model based control methods.

The closed loop performance of the ball and beam system will be analysed using fuzzy logic and also the entire system will be implemented as hardware prototype. Then the comparison will be made between the hardware and software results.

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