International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 2 Issue 6, June - 2013

Adaptive Fuzzy PID For The Control Of Ball And Beam System

Shabeer Ali K P[1], Dr. Vijay Kumar[2]
[1] Student , E & CE Department, IIT Roorkee ,Roorkee , India
[2] Professor, E & CE Department, IIT Roorkee ,Roorkee , India

***Abstract*— This paper introduces an effective approach about the self-adaptive fuzzy PID control and fuzzy control. Apply the control method in Googol's GBB1004 ball and beam system and the implementary results sufficiently demonstrates its validity and realizes the effective control for the ball and beam system.**

***Index Terms*—Ball and beam system, Adaptive fuzzy logic controller.**

I. INTRODUCTION

Control of a Ball and Beam system is one of the most interesting and classical problems for control engineering. The objective of this project is to design a controller which is capable of controlling the Ball and Beam system. The ball and beam system can usually be found in most university control labs since it is relatively easy to build, model and control theoretically. The system includes a ball, a beam, a motor and several sensors. The basic idea is to use the torque generated from motor to the control the position of the ball on the beam. The ball rolls on the beam freely. By employing linear sensing techniques, the information from the sensor can be taken and compared with desired positions values. The difference can be fed back into the controller, and then in to the motor in order to gain the desired position. The mathematical model for this system is inherently nonlinear but may be linearised around the horizontal region. This simplified linearised model, however, still represents many typical real systems, such as horizontally stabilizing an airplane during landing and in turbulent airflow. By considering real plant problems such as the sensor noise and actuator saturation, the controllers of the system become more efficient and robust.

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II. THE BALL AND BEAM SYSTEM MODEL

A ball is placed on a beam, see figure below, where it is allowed to roll with 1 degree of freedom along the length of the beam. A lever arm is attached to the beam at one end and a servo gear at the other. As the servo gear turns by an angle theta, the lever changes the angle of the beam by alpha. When the angle is changed from the horizontal position, gravity causes the ball to roll along the beam. A controller will be designed for this system so that the ball's position can be manipulated.

For this problem, we will assume that the ball rolls without slipping and friction between the beam and ball is negligible. The constants and variable for this example are defined as follows:

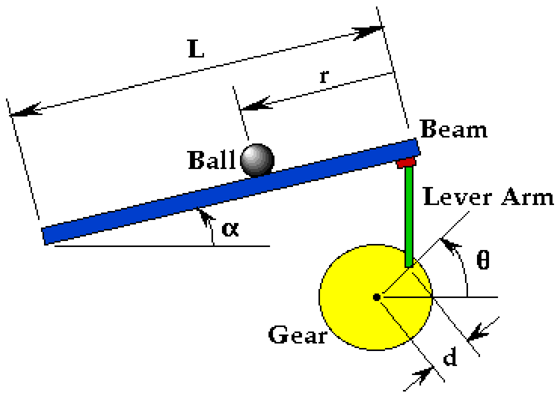

Figure 1: Ball and Beam model

In this, rather than express all the forces and geometric constraints (which is difficult to model in Simulink for dynamic systems with constraints) we will model the nonlinear Lagrangian equation of motion directly. This equation gives d/dt(r) as a function of the state and input variable, r, d/dt(r), alpha, and d/dt(alpha). We will make use of the Nonlinear Function Block to express this function. First, we must express the derivatives of the output, r.

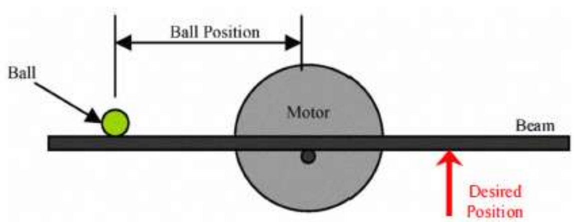

Figure 2: Simplified model for Ball and Beam System.

The system diagram given in Fig. 1 shows that there are three main components are involved in the system which includes moments and forces acting on them, the motor, the beam, and the ball. To simplify the design, the motor shaft and beam are considered to be the rigid body (i-e the stiffness across the transmission to be near the plane of ball contact, and there is no skidding). The sum of forces at the point of intersection can be written as,

$$\sum Fb = mgsin\emptyset - Fr - m\ddot{x} \qquad (1)$$

Where the subscript b denotes forces acting on the ball, m is the mass of the ball, g is gravity, Fr is the rolling constraint forces on the ball and x is the position of the ball along the beam. By geometry, the position can be defined as,

$$x=\alpha * a' \qquad (2)$$

Where α is the angular displacement of the ball, and a' is the distance between the axis of rotation of the ball and point of contact of the ball with the beam. The torque balance of the ball, T b is also a product of the rolling constraint force as,

$$Tb=Fr*a'=Jb*\ddot{\alpha} \qquad (3)$$

$$Jb=m*a^2 \qquad (4)$$

Where Jb is the moment of inertial of the ball, and a is the radius of the ball.

The torque balance is given by,

$$\sum Tbm=Jbm\ddot{\emptyset} \qquad (5)$$

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Where the subscript bm denotes the beam and motor, and Tbm represents the torque generated by the motor. The torque relation is given by ,

$$\text{Tin=Kt*Iin} \qquad (6)$$

Where K, is motor torque constant, and lin is the current supplied to the motor.

From (6), it can be shown that a linearized model at 0° can be written as,

$$\text{Gbb}=\frac{\emptyset(s)}{Iin\,(s)} = \frac{g}{s^2(1+0.4\left(\frac{a}{a'}\right)^2)}$$

(7)

Where 'a' is the angular displacement of the ball and (a') is the diameter of the ball used and (g) is gravity.

Based on the motor parameters, Km=O. 7Irevlsecivolts, T =0.014 sec, J=1. 4x 10.6 Kg_m2, motor model can be written as,

$$\text{Gm}=\frac{\theta(s)}{\text{Iin}\,(s)} = \frac{0.7}{s(0.014s+1)}$$

(8)

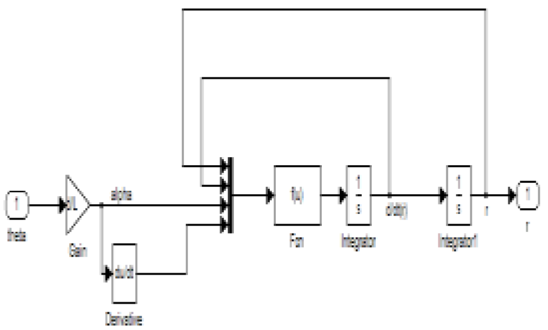

Figure 3: Ball and Beam nonlinear model.

III. CONTROL STRATEGY

Adaptive Fuzzy PID Controller:

The self-adaptive fuzzy PID control principle can be described as follows:

$$m(t) = (Kp + \Delta Kp)e(t) + (Ki + \Delta Ki)\int_0^t e(t)dt + (Kd)e(t)/dt \qquad (2.6)$$

Where *Kp,Ki,Kd* are initial PID parameters, and Δ*Kp and ΔKi* are PID tuning variables obtained via fuzzy inference. In this article three double-input and single output fuzzy controllers are designed to timely adjust *Kp, Ki*. The fuzzy controller inputs are *e* and *ec* and their outputs are respectively *Kp, ki,* (2.7) *Kd*. And in this paper, *e,ec* and *Kp, Ki* are all divided into seven fuzzy sets, and linguistic variables [*NB NM NS ZE PS PM PB*] are adopted for fuzzy sets chosen before. *e,ec* are converted into fuzzy domain [-6 6] via quantization factors and fuzzy domain [-10 10] is corresponding to *Kp, Ki, Kd*. In order to make sure the input and output variable's states don't change abruptly overlapping and triangle-shaped membership functions (MFS) are used to describe each fuzzy set. The regulating rules of *Kp, Ki, Kd* according to different *e,ec* are as follows:

When |e| is much large choose larger dK_p to eliminate error immediately and improve response of the system and choose a little bit small dK_d and to avoid oscillation define dK_i as zero.

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When e•ec>0 - In this case if |e| is much large we have to take larger dK_p, a little bit small dK_i and medium dK_d. When |e| is small, use medium dK_p, a little large dK_i and small dK_d. Here the given value is deviating from the controlled value causing the system oscillating and becomes less stable.

When *e•ec*<0, the controlled value changes towards the given value. If |*e*| is much large it is suitable to select medium *Kp,Kd* and small *Ki* to improve system's dynamic features and stability. In contrary, if |*e*| is very small it is recommended to select small *Kp,Kd* and larger *Ki*.

ec indicates the error change rate, thus when *ec* is larger it is appropriate to choose smaller *Kp* and larger *Ki*.

e ec

ΔKp	NB	NM	NS	ZE	PS	PM	PB
NB	PB	PB	PM	PM	PS	ZE	ZE
NM	PB	PB	PM	PS	PS	ZE	NS
NS	PM	PM	PM	PS	ZE	NS	NS
ZE	PM	PM	PS	ZE	NS	NM	NM
PS	PS	PS	ZE	NS	NS	NM	NM
PM	PS	ZE	NS	NM	NM	NM	NB
PB	ZE	ZE	NM	NM	NM	NB	NB

Table1:Fuzzy rule base for ΔKp

e ec

ΔKi	NB	NM	NS	ZE	PS	PM	PB
NB	PS	PS	ZE	PM	PS	PM	PB
NM	PS	PS	ZE	PS	ZE	NS	NS
NS	ZE	ZE	ZE	PS	NS	NS	NM
ZE	PB	PM	PS	ZE	NS	NM	NB
PS	PM	PS	ZE	NS	ZE	NS	NM
PM	PS	ZE	PS	NM	ZE	NS	NS
PB	NB	NM	NS	NM	ZE	NS	NS

Table2:Fuzzy rule base for ΔKi

e ec

ΔKd	NB	NM	NS	ZE	PS	PM	PB
NB	PM	PM	PS	PM	NS	NM	ZE
NM	PM	PM	PS	PS	NS	ZE	NM
NS	PS	PS	PS	PS	ZE	NS	NS
ZE	PM	PM	PS	ZE	NS	NM	NM
PS	PS	PS	ZE	NS	NS	NS	NS
PM	PM	ZE	NS	NS	NS	NM	NM
PB	ZE	NS	NS	NM	NM	NM	NM

Table3:Fuzzy rule base for ΔKd

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IV. SIMULATION AND REAL TIME EVALUATION OF SELF-ADAPTIVE FUZZY PID CONTROLLER

The initial PID parameters obtained by experimental method. It is worth noting that differential item exists in mathematical model of IP system. It is therefore facile for the IP system to cause high-frequency noise and lead to decline

the anti-disturbance capability. Taken these issues and system's dynamic nature into account, when choosing differential weighting coefficients, it is recommended to select a small Kd. In the end, it is obtained that Kp=6, Ki=0.2, Kd=5 via trial and error approach. Quantization factors and scale factors of self-adaptive fuzzy PID controller are Ke=4, Kec=20, Kpu=0.05, Kiu=0.05, Kdu=-0.25. These parameters are obtained after continuously simulating and experimenting.

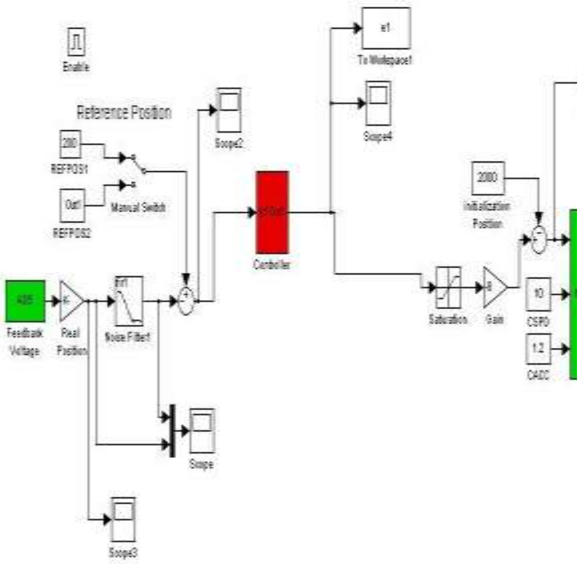

Figure 5: Ball and Beam Real time controller.

V. RESULTS

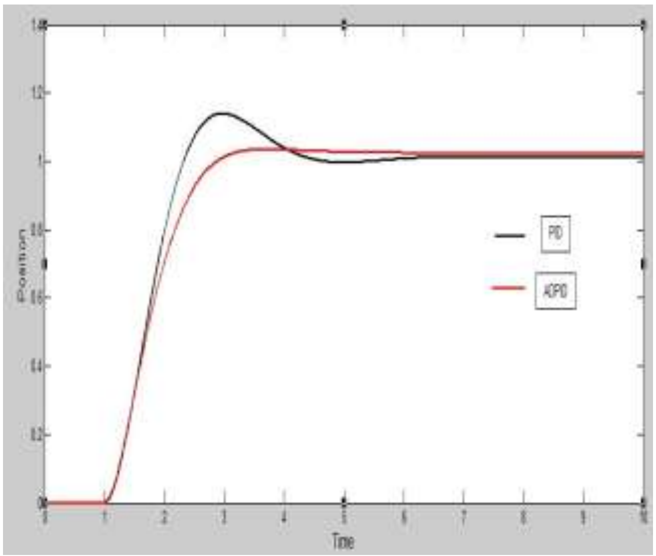

Figure 5: Ball and Beam unit response of non-linear model

In real time control as expected ball maintained in balance state in 3.5 sec in the reference position.

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VI. CONCLUSION

this paper presents Self adaptive fuzzy PID controller for the ball and beam system. The effectiveness of the proposed controller has been investigated through simulation studies and in real time. The simulation shows a better performance compared to PID. The proposed controller is more robust compared PID. The simulation results are validated with the experimental real time model of googol's magnetic levitation system.

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