# REAL TIME EXPERIMENT TO SETUP THE BALL AND BEAM SYSTEM

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**ABSTRACT**

The proposed paper carries out experiments to explore suitable control techniques to setup a real time Ball and Beam system with the help of a Quanser Servo motor. **Methods/Statistical analysis**: To develop an efficient controller, modelling of the system is significant which is accomplished using frequency response method with the Quarc toolbox. A fuzzy logic controller is designed to enhance the ball and beam system's response. A classical PD controller is also employed to understand better the functioning of a non-linear controller such as the designed fuzzy controller. These controllers are implemented using QUARC toolbox in simulink MATLAB. Determining the behavior of a controller involving a non-linear system is a tedious task to test and develop. To stabilize the ball on the beam, the control systems are employed in such a way as to measure the position of the ball which is taken as the feedback signal in order to adjust the beam angle accordingly. The performance results between the two controllers are compared. While the designed PD controller showed good performance, it is obvious that in case of few parameter changes of the system it led to the decline of the controller's performance drastically. Thus, revealing the dire need of an intelligent controller such as the fuzzy controller than the PD controller which stabilizes the system efficiently and that the ball is controlled steadily. **Improvements:** The proposed controller is designed in such a way that it targets in the improvement of timing performance of the controller as well as better stability of the ball on the beam.

***Keywords****— PD controller(PD), Fuzzy logic controller (FLC), Ball and beam(BB), Quarc toolbox, Matlab/Simulink*

## 1. INTRODUCTION

The ball and beam system are branded to be the benchmark for different control system techniques[1].The Quanser module consists of a steel ball rolling on the top of the beam. When the system is simulated the motor, shaft rotates randomly without any control. The goal is to position the freely running ball at a desired position on the beam which is a challenging process.

A Quanser servo module with QUARC toolbox is used to derive the transfer function of the servo using frequency response method[2]. The obtained transfer function describes the rotary motions of the load shaft. The servo motor is connected to one end of the beam through a gear mechanism to control the position of the ball on the beam[3-5]. A linear sensor on the beam continuously detects the ball position. Initially the Quanser servo is connected with the Volt-PAQ x1 power supply module which gives the supply to the motor. The encoder and the tachometer signals can also be obtained using this power supply module. The control problem requires moving the ball from one position on the track to another by controlling the beam angle. The control system is implemented using a computer interfaced to the ball and beam system via a DAQ Q8-USB[3-5]. Computer inputs are acquired from the voltage signals proportional to the ball position. The computer output voltage controls the motor that changes the beam angle. In this work, the fuzzy logic controller will be realized for enhancing the response by the ball and beam system. Thus, the robust control of the plant is obtained with the help of this Quarc toolbox of Matlab software.

Fig 1 : Quanser Ball and Beam setup

## 2. MODELING OF QUANSER SERVO MOTOR EXPERIMENTALLY

For a control design process it is necessary to develop suitable mathematical models of the system either by deriving them from physical laws or from experimental data. System modeling can be done either using Bumptest method or Frequency response method[2]. In section 2.1, frequency response method is discussed.

***2.1 Frequency Response Method:*** The frequency response is an important tool for analysis and represents the response of the system at varying frequencies for sinusoidal inputs. For a linear system, the given sinusoidal input will have a similar output of the same frequency but with a different magnitude and phase. However, it has advantages, particularly in real-life situations, for example modeling of transfer functions from physical data etc.

By varying the frequency and observing the outputs, a bode plot of the system can be achieved. In Frequency response method, the input offset voltage is kept as small as possible to minimize the error at output. In this experiment, input signal is the motor voltage and output signal is the motor speed. To create a Bode magnitude plot the ratio of the output and input amplitudes for the given frequency can be used. Then, the transfer function for the system can be extracted from this plot[2,4,15-16].

***2.1.1 Procedure:***

Initially, the steady-state gain of the system is to be calculated by operating the system with a constant input voltage of 2V. The subsequent steps has to be followed [2,4,15-16]:

1.In the Simulink diagram, ensure that the following parameters are set accordingly[2,4,15-16]:

For the 'Signal Generator' block

- Signal type: sine wave
- Frequency: 0.0
- Amplitude: 1.0
- Unit: Hertz

For the Offset block : 2.0 V

2. Build the simulink to compile the model diagram.

3.For SRV02 unit to begin rotating the 'Connect To Target' icon is clicked.

4.Measure the load shaft speed and note down the measurement in Table I, under the f (Hz) row.

5.Open the load shaft speed and the motor input voltage scopes to directly read the maximum load speed.

From the scope, it is observed that the yellow trace is the measured speed and the purple trace is the simulated speed.

***2.1.2 Response Of The System:*** *The corresponding gain values are calculated for the recorded motor speed by varying the frequency of the sine wave input[2,4] .*

Table 1: Obtained frequency response data

| f(Hz) | Amplitude (V) | Maximum Load Speed(rad/s) | Gain (rad/s/V) | Gain (rad/s/V,dB) |
|---|---|---|---|---|
| 0.0 | 2.0 | 3.31 | 1.66 | 4.40 |
| 1.0 | 2.0 | 3.23 | 1.61 | 4.13 |
| 2.0 | 2.0 | 3.15 | 1.57 | 3.91 |
| 3.0 | 2.0 | 2.96 | 1.47 | 3.34 |
| 4.0 | 2.0 | 2.77 | 1.38 | 2.79 |
| 5.0 | 2.0 | 2.54 | 1.29 | 2.21 |
| 6.0 | 2.0 | 2.43 | 1.22 | 1.72 |
| 7.0 | 2.0 | 2.34 | 1.17 | 1.36 |
| 8.0 | 2.0 | 2.22 | 1.11 | 0.90 |

***2.1.3 Transfer Function***

Magnitude of Frequency response of SRV02 plant transfer function is

$$|G_{wl,v}(\omega_j)| = \frac{\Omega_l(\omega_j)}{V_m(\omega_j)}$$

where, **ω** is the frequency of the motor input voltage.

Thus, for f=1Hz the maximum load speed is 0.3369 and the voltage is 0.2V. Therefore Gain is

$$|G_{wl,v}(0)| = 1.66[rad/s]$$

The Gain in dB is,

$$|G_{wl,v}(0)|_{dB} = 20log10(1.66) = 4.40dB$$

The -3dB Gain is,

$$|G_{wl,v}(\omega_c)|_{dB} = 1.52dB$$

From the bode plot the cut-off frequency is $f_c$=6.6 Hz.

$$\omega_c = 2\pi f_c$$

$$\omega_c = 41.469[rad/s]$$

Time constant is,

$$\tau = \frac{1}{\omega_c} = 0.0226 \text{ s}$$

Thus the transfer function of the system is,

$$\frac{\Omega_l(s)}{V_m(s)} = \frac{1.66}{0.0226 s+1}$$

**3. DESIGN METHODOLOGY OF PD CONTROLLER**

The whole Ball and beam system [3-4] consists of two loops: (1) Inner loop is the servo motor control loop (2) outer loop is the ball and beam loop. The design plan is to stabilize the inner loop first followed by an outer loop control. The PD controller was designed for the ball and beam loop. Figure 2 shows the simulink subsystem block diagram designed in QUARC toolbox of MATLAB using the PD controller.

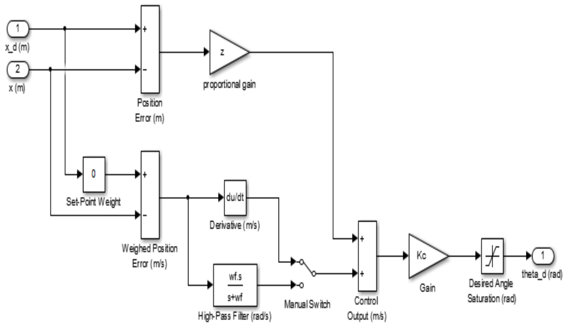


Fig. 2: Subsystem Block diagram of Ball and Beam setup using PD

The position of the ball when measured by the sensor has some inherent noise. The derivative of this type of signal would result in an amplified high-frequency signal that is fed back into the motor thus causing a grinding noise. This is prevented by using a high-pass filter. In addition, a saturation block that limits the servo angle between ±56 degrees is used[3-4].

**4. DESIGN OF FUZZY LOGIC CONTROLLER**

While PID is an effective technique implementing control methodology of non-linear systems, however it is often very complicated and time consuming. However, the Fuzzy Logic Control, provides a better alternative for a robust and cost-effective servo-controller. Although the efficiency of fuzzy controller is similar to that of a conventional controller: the significant difference is evident in its work time, where the fuzzy control is faster.[6-12]

The simulation part is performed with the MATLAB program package and the additional QUARC Toolbox has been used for the real-time experiment's. The QUARC Toolbox is a package associated with MATLAB and the data is attained in real time from the surrounding and direct action is taken to the outside world.

The design procedure employs simple fuzzy rules which is defined in MATLAB. For defuzzification and fuzzification process, the centroid method and the triangular membership functions are used for both input as well as the output respectively[6,12-14]. Their universe of discourse is given as[1,5]:

- e = [-1,1]
- de=[- 1,1]
- V= [-2, +2]

### *4.1 Membership Functions*

The system is designed for two types of input and the results for two cases are observed. The fuzzy rules are identical in both the cases where each fuzzy set consists of seven membership functions, which is denoted as NB, NM, NS, ZE, PS, PM and PB[1].

where NB is negative big, NM is negative medium, NS is negative small, ZE is zero, PS is positive small, PM is positive medium and PB is positive big.[15-16]

***4.2 Rule Base:*** Fuzzy control rules is crucial for a fuzzy controller. The design for the rule base closely follows the one mentioned in the given Table 2[1].

Table 2: Fuzzy Rules

| e/ ė | PL | PM | PS | Z | NS | NM | NL |
|---|---|---|---|---|---|---|---|
| **NL** | Z | NS | NM | NL | NL | NL | NL |
| **NM** | PS | Z | NS | NM | NL | NL | NL |
| **NS** | PM | PS | Z | NS | NM | NL | NL |
| **Z** | PL | PM | PS | Z | NS | NM | NL |
| **PS** | PL | PL | PM | PS | Z | NS | NM |
| **PM** | PL | PL | PL | PM | PS | Z | NS |
| **PL** | PL | PL | PL | PL | PM | PS | Z |

### *4.3 Simulink*

Simulation Model of the fuzzy controller of a ball and beam setup is shown in figure 3. This model is built in MATLAB 2013b and is controlled.

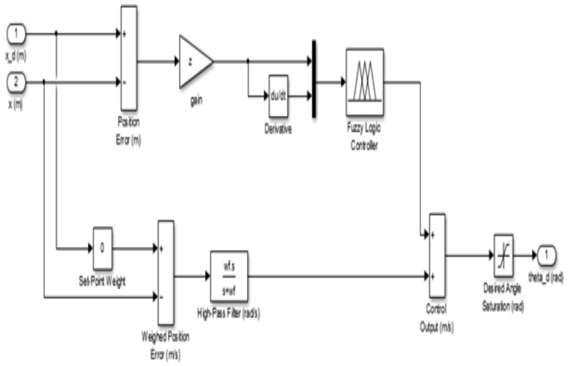


Fig - 3: Subsystem Block diagram of Ball and Beam setup using FLC

## 5. RESULTS AND DISCUSSION

Figure 4 represents the x (cm) scope which is the ball position scope where the simulated ball position response is plotted for both PD and FLC controllers. From the plots, we infer that a steady settling of the response is acquired, and it is similar to the desired output. Through observing the experimental results, it is noted that the peak overshoot of FLC has been drastically reduced to 0.619% when compared to 10.8% overshoot of the PD controller. While the settling time for both the systems is almost the same.

Table 3: Summary of output responses by PD and FLC controllers

| S.No | PARAMETERS | PD | FLC |
|---|---|---|---|
| 1. | Peak time | 2.27 s | 4.33 s |
| 2. | Percentage overshoot | 10.8 % | 0.619 % |
| 3. | Settling time | 3.45 s | 3.34 s |
| 4. | Steady state error | $3.09\text{x}10^{-4}$ | $7.2\ \text{x}10^{-6}$ |

Similarly figure 5 represents the theta l (deg) scope, where the desired servo angle position is generated by the outer-loop control, and the simulated servo responses of the both the controllers are plotted. And figure 6 is the SRVO2 Motor input voltage scope Vm(V). The comparative study between the two controllers indicates the superiority of the proposed Fuzzy controller in the aspect of performance robustness.

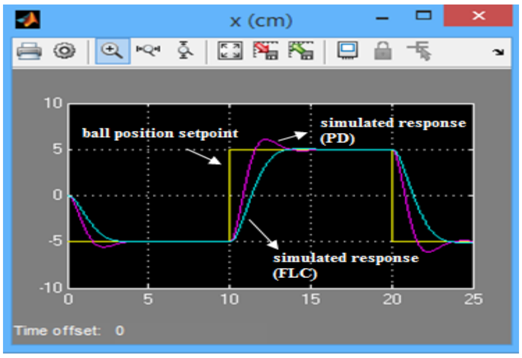


Fig. 4: Ball position x(cm)

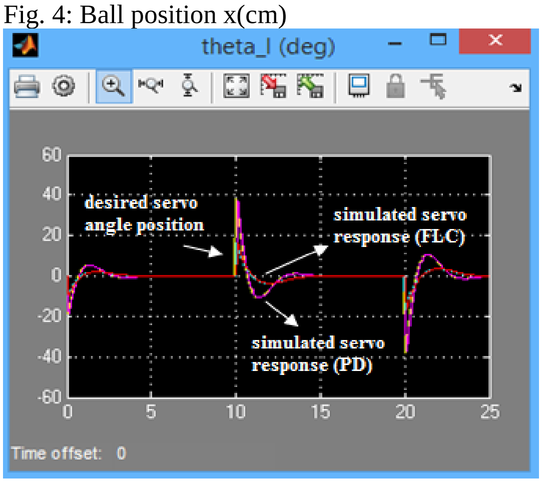


Fig 5: Servo angle theta_l(deg)

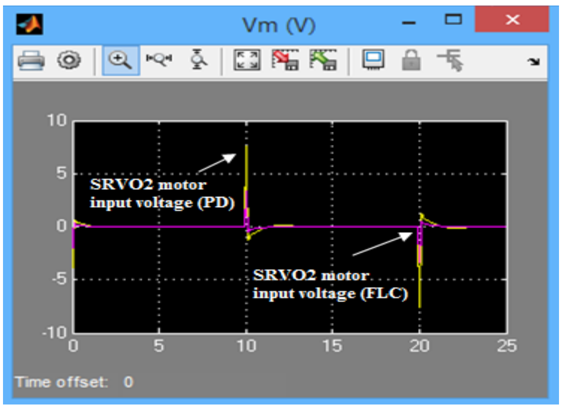


Fig. 6: SRVO2 Motor input voltage Vm(V)

## 6. CONCLUSION

The paper presented modeling and control of the ball and beam system. Using Frequency Response method, the transfer function of Quanser servomotor is obtained which is necessary in achieving the robust control of a non-linear system. A PD controller and fuzzy logic control was designed to get the ideal stability. The system was designed using two types of input for FLC and the results were observed in both the cases where it is clear that fuzzy logic gives a smooth and effective controller when compared to that of a classical PD controller. The output response of FLC gives very limited error and more quality response and is considered to highlight the robustness of the ball and beam system.

Further research could be made along the field of neural network or with an optimized fuzzy PID controller.

## ACKNOWLEDGMENT

The authors would like to thank SRM University for providing the sponsorship and the facilities in conducting of this research.

## REFERENCES

M. Amjad, M, KashifM.I, S.S. Abdullah and Z. Shareef, Fuzzy Logic Control of Ball and Beam System. 2nd International Conforence on Education Technology and Computer (ICETC). (2010).

[2] Bri Andha, A., S. Balamurugan and P. Venkatesh, Real Time Experiment to Determine Transfer Function of Quanser Servo Plant. International Conference on Recent Advancements in Electrical Electronics and Control Engineering (2011).

[3] Markham, Ontario. Quanser Ball and Beam Manual Setup and Configuration (2011)

[4] Markham, Ontario, Quanser SRVO2 User Manual Setup and Configuration (2015)

[5] Ball and Beam 1: Basics Peter Wellstead: control systems.co.uk. Available from: http://www.control systemsprinciples.co.uk/whitepaperslball-and-beam (2015)

[6] Kumar S.T., Jaganatha Pandian B. Tuning and Implementation of Fuzzy Logic Controller using Simulated Annealing in a Non-Linear Real time System. International Conference on Circuit, Power and Computing Technologies [ICCPCT]. 2014.

[7] Abdulrahman A., A. Emhemed, Fuzzy Control For Nonlinear ball And Beam System. International Journal of Fuzzy Logic Systems (IJFLS). (2013)

[8] Senthilkumar, S., P. Suresh, S. Senthilkumar, Performance Analysis of MIMO Ball and Beam System using Intelligent Controller. International Journal of Computer Applications® (IJCA). (2012).

[9] Keshmiri, Jahromi, Mohebbi, Amoogar, g Xie. Modeling and control of Ball and Beam system using model based and non-model based control approaches. International Journal on Smart Sensing And Intelligent Systems 5(1): (2012).

[10]FuaadRahmat M, Wahid H, Abdul WahabN. Application of Intelligent Controller In A Ball And Beam Control System. International Journal on Smart Sensing and Intelligent Systems 3(1): 45-60 (2010).

[11] Beibei H, Yan G. Variable Universe Fuzzy Controller with Correction Factors for Ball and Beam System. Intelligent systems and Applications (2011).

[12] Houshyar Asadi, Arash Mohammadi., Maysam Oladazimi. Stabilization Ball and Beam by Fuzzy Logic Control strategy. Fourth International Conference on Machine Vision (ICMV) (2011).

[13] J.Hauser, S. Sastry, P.Kokotovi. Nonlinear Control via approximate input-output linearization: the ball and beam example. IEEE Transactions on Automatic Control. 37(3): 392-398 (1992).

[14] Wen Yu, P.D.Nonlinear, regulation for ball and beam system. International Journal of Electrical Engineering Education 46(1): 59-73 (2009).

[15] Merin Mary Sabu, A. Brindha, A.Vimala Juliet. Design of Fuzzy with PID Control of a Non-linear system. unpublished.

[16] Merin Mary Sabu, A.Brindha, A.Vimala Juliet. Design of Non-linear controller for a Ball and Beam setup. unpublished.