JEEEIT TRANSACTIONS, Vol.02,No.01,December 2025

# Comparative Evaluation of Control Techniques for a Ball and Beam System Using LabVIEW

**Shahed Mohammed Esmail[1], and Safa Mohammed Esmail[1]**
[1]Control Engineering Department, College of Electronic Technology, Bani Walid, Libya
Corresponding author: shahedesmail071@gmail.com

**ABSTRACT** This paper presents a comparative study of different control strategies applied to the Ball and Beam system which is inherently nonlinear and open-loop unstable and the system was mathematically modeled and linearized to derive its transfer function and four controllers were designed and evaluated namely a PID controller using the Ziegler–Nichols method a PID controller using the Tyreus–Luyben method an Internal Model Control-based PID controller and a Fuzzy Logic Controller and all controllers were implemented and simulated in LabVIEW to ensure consistent and reliable performance evaluation and they were compared using time-domain performance indicators including rise time settling time overshoot and steady-state error and simulation results showed that conventional PID controllers could stabilize the system but exhibited high overshoot and long settling times with the Tyreus–Luyben PID outperforming the Ziegler–Nichols PID in response speed and overall performance while the IMC-PID controller achieved zero overshoot and rapid settling and the Fuzzy Logic Controller provided smooth and stable response without requiring an accurate mathematical model.

**KEYWORDS** Ball and Beam System, PID Control, IMC, Fuzzy Logic, LabVIEW.

## I. INTRODUCTION

The Ball and Beam system is a classical benchmark in control engineering due to its nonlinear behavior and inherent open-loop instability [1][3]. In this system, a steel ball rolls on a beam whose tilt is controlled by a servo motor. The ball's position increases without bound for a fixed beam angle, making the system highly unstable and challenging to control [1][3]. These characteristics are representative of many real-world complex systems, including vertical take-off aircraft and precision industrial processes, making the Ball and Beam system an ideal platform for evaluating and comparing different control strategies [4][5].

Conventional PID controllers are widely used to stabilize the Ball and Beam system due to their simplicity and effectiveness in nonlinear systems [4][5]. Among PID tuning methods, the Ziegler–Nichols (ZN) approach is commonly applied to determine proportional, integral, and derivative gains based on the system's ultimate gain and oscillation period [2]. However, PID controllers tuned using the ZN method may produce significant overshoot and oscillations, particularly in highly nonlinear systems [2]. The Tyreus–Luyben (TL) PID method addresses these limitations by adjusting the integral and derivative time constants while maintaining the ultimate gain and period, thereby improving system performance and reducing oscillations [6][7]. Furthermore, Narong Aphiratsakun and Nane Otaryan demonstrated that PID tuning using MATLAB/Simulink or trial-and-error methods can achieve accurate and reliable control for the Ball On The Plate system, a nonlinear balancing platform analogous to the Ball and Beam system [6].

In addition to conventional PID methods, Fuzzy Logic Controllers (FLCs) have been applied as a promising alternative for nonlinear systems [1][5]. FLCs do not require an explicit mathematical model; instead, they leverage expert knowledge in the form of if–then rules to map system inputs to outputs, making them particularly suitable for highly nonlinear systems like the Ball and Beam [1][5]. Studies have shown that hybrid Fuzzy-PID controllers outperform conventional PID controllers in terms of overshoot, settling time, and steady-state error, especially under external disturbances or parameter uncertainties [1][5].

In this study, the Ball and Beam system is analyzed and compared using four control strategies: Ziegler–Nichols PID, Tyreus–Luyben PID, IMC-based PID, and Fuzzy Logic Controller. The performance of each controller is evaluated in terms of stability, transient response, steady-state error, settling time, rise time, overall system stability, and robustness. All simulations and implementations are performed in LabVIEW/Simulink, using the system's transfer function to ensure accurate performance evaluation within a real-time simulation environment.

Received October 2025, Received in received from November 2025, Accepted December 2025, and Published December 2025 

## II. SYSTEM MODELING

The Ball and Beam system is a classic example of an inherently unstable system with a single degree of freedom, where the ball moves along the beam under the influence of gravity. The beam is connected to a lever at one end and a servo motor at the other. When the servo motor rotates by an angle θ, the lever adjusts the beam angle by α. This change in the beam angle converts a component of the gravitational force into motion along the beam, causing the ball to roll. To control the ball's position, a suitable controller is designed to adjust the servo motor angle so that the ball remains precisely at the desired position, as shown in Figure 1.

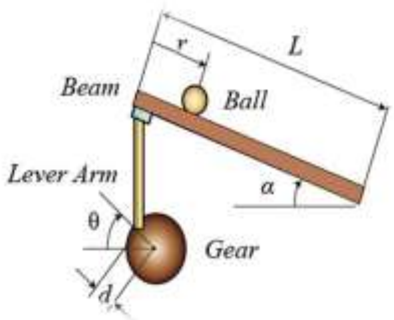


**FIGURE 1. Ball and beam model.**

The Lagrangian equation of motion for the ball is given by the following:

$$\left(\frac{J}{R}+m\right)\ddot{r} = -mg\sin(\alpha) + mr(\dot{\alpha})^2 \tag{1}$$

Linearization of this equation about the beam angle, alpha = 0, gives us the following linear approximation of the system:

$$\left(\frac{J}{R^2}+m\right)\ddot{r} = -mg\alpha \tag{2}$$

The equation which relates the beam angle to the angle of the gear can be approximated as linear by the equation below:

$$\alpha = \left(\frac{d}{L}\right)\theta \tag{3}$$

Substituting equation (3) into (2), so we get:

$$\left(\frac{1}{R^2}+m\right)\ddot{r} = -mg\left(\frac{d}{l}\right)\theta \tag{4}$$

Taking the Laplace transform of the equation above, the following equation is found:

$$\left(\frac{1}{R^2}+m\right)R(s)\cdot s^2 = -mg\left(\frac{d}{L}\right)\theta(s) \tag{5}$$

Divide equation (5) per (s) to get the ball position R(s)to the gear angle (s).

$$\frac{R(s)}{\theta(s)}\left(\frac{\theta}{R^2}+m\right)\cdot S^2 = -mg\left(\frac{d}{L}\right)\left(\frac{\theta(s)}{\theta(s)}\right) \tag{6}$$

$$\frac{R(s)}{\theta(s)} = -\frac{R^2\, mg\, d}{(LJ + R^2 Lm)s^2} \tag{7}$$

The parameter specifications of the Ball and Beam system employed in this study are summarized in Table **1** and will be substituted into equation (7) to derive the corresponding transfer function [7].

TABLE I
SPECIFICATIONS OF BALL AND BEAM SYSTEM

| Abbreviation | Quantity | Value | Units |
|---|---|---|---|
| (g) | gravitational acceleration | -9.8 | $m\ /\ s^2$ |
| (R) | Radius of ball | 0.02 | m |
| (L) | Length of beam | 0.34 | m |
| (m) | mass of the ball | 0.0026 | $kg$ |
| (d) | Lever arm offset | 0.05 | m |
| (J) | Moment of inertia of ball | $\frac{2\times m\times R^2}{5}$ | $kg * m^2$ |

From Table 1 [8] , the ball and beam system transfer function can be simplified by (8):

$$\frac{R(s)}{\theta(s)} = \frac{1.029}{s^2} \tag{8}$$

The Root Locus illustrates the movement of the poles of the Ball and Beam system as the gain varies. It can be observed that at K=1, the poles lie on the imaginary axis, indicating a condition of marginal stability. At this operating point, the system exhibits high-amplitude oscillations with insufficient damping, as shown in the Figure 2.

Therefore, it became necessary to employ appropriate controllers to increase system damping and shift the poles into the left half of the complex plane, thereby ensuring full stability and improved dynamic performance.

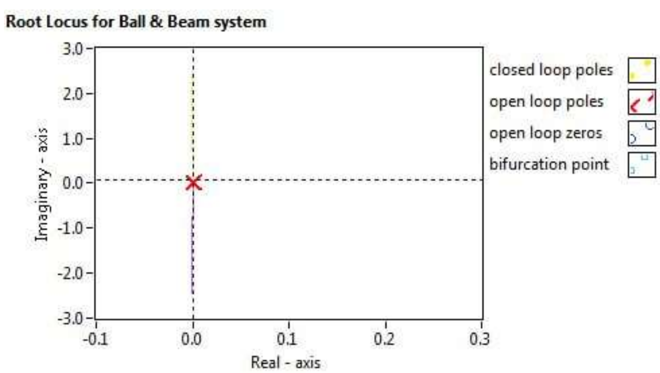


**FIGURE 2. Root Locus plot of the Ball and Beam system without controller**

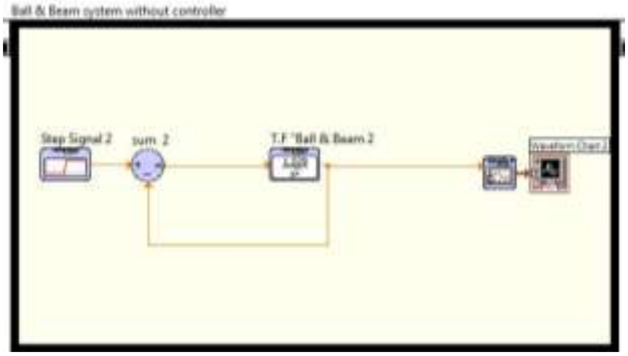


FIGURE 3. **LabVIEW simulation of the Ball and Beam system without controller**

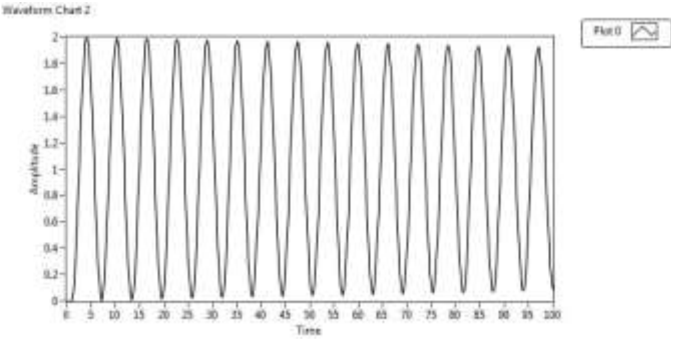


FIGURE 4. **Dynamic response of the Ball and Beam system without controller.**

## III. MATH

### A. PID CONTROLLER

A Proportional–Integral–Derivative (PID) controller is a linear feedback control mechanism widely used in industrial applications. The controller continuously computes the error, defined as the difference between the setpoint and the current process variable, and attempts to minimize it by adjusting the control input.

In the context of our control system, the control input is the beam angle, which is regulated by the PID controller to maintain the desired position of the ball along the beam.[8]

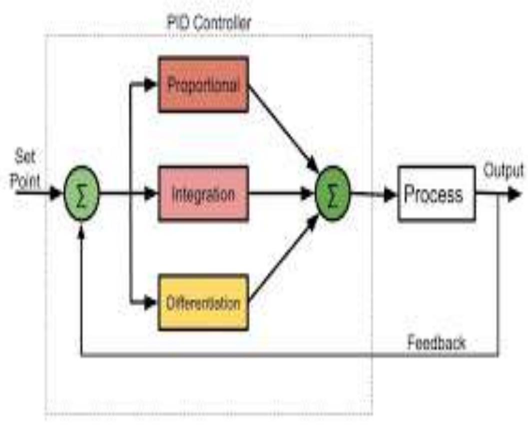


FIGURE 5. **General system with P, PI and PID controllers unity feedback.**

The transfer function of PID controller is shown below:[9]

$$G_C(s) = k_p + \frac{k_I}{s} + k_D s \tag{9}$$

$$G_C(s) = k_C\left(1 + \frac{1}{T_i s} + T_d s\right) \tag{10}$$

*PID Controller Tuning Using Ziegler–Nichols and Tyreus–Luyben Methods*

The PID controller tuning is performed using both the Ziegler–Nichols and Tyreus–Luyben ultimate gain methods. In these approaches, the ultimate gain $k_u$and the corresponding ultimate period $p_u$ are first determined by adjusting the proportional gain until sustained oscillations are observed in the closed-loop system. The obtained values of $k_u$and $p_u$are then used to compute the PID tuning parameters according to the Ziegler–Nichols and Tyreus–Luyben tuning rules, respectively, enabling a comparative evaluation of the controller performance.

The closed-loop characteristic equation of the system is given by: [9]

$$1 + kG(s) = 0 \tag{11}$$

Substituting the system dynamics into the characteristic equation results in:

$$s^2 + 1.029k = 0 \tag{12}$$

To determine the stability boundary and evaluate the ultimate gain, the **Routh–Hurwitz stability criterion** is applied. According to this criterion, the system is stable if and only if all the elements in the first column of the Routh array are positive. At the stability limit (marginal stability), the element in the first column of the $s^1$ row becomes zero:

**1.ultimate gain** $Ku$

$$1.029k = 0 \tag{13}$$

**Note:** For the purpose of this study, the ultimate gain $k$ is assumed to be 1 then $k_u = 1.029$, This assumption simplifies the initial tuning of the PID controller and is justified by the fact that the system is marginally stable, so any positive gain induces sustained oscillations.

**2.ultimate period** $Pu$

$$Pu = \frac{2\pi}{\omega} \tag{14}$$

From the $s^2$equation in the Routh array, the gain $k = 1$ substituted to determine the angular frequency $\omega_u$ of the sustained oscillation.

Let $s = j\omega$

$$-\omega^2 + 1.029 = 0 \qquad (15)$$

$$\omega = \pm 1.0144 \qquad (16)$$

$$Pu = 6.194\ sec \qquad (17)$$

### *A.1 Ziegler–Nichols PID Controller*

By substituting the ultimate gain $ku$ and ultimate period $p_u$, the PID controller parameters in equation 9 are determined.

$$k_P = k_c = 0 \cdot 6174 \qquad (18)$$

$$k_i = \frac{k_c}{Ti} = 0 \cdot 1994 \qquad (19)$$

$$k_D = kT_d = 0.478 \qquad (20)$$

$$G_c(s) = 0 \cdot 6174 + \frac{0 \cdot 1994}{s} + 0 \cdot 478s \qquad (21)$$

TABLE II
CONTROLLER PARAMETERS IN THE ZIEGLER-NICHOLS CLOSED-LOOP METHOD [6]

| | $k_c$ | $T_i$ | $T_d$ |
|---|---|---|---|
| PID controller | $0.6ku$ | $\frac{Pu}{2}$ | $\frac{Pu}{8}$ |
| Value | 0.6174 | 3.097 | 0.7743 |

#### *A.1.1* LabVIEW-Based Analysis of PID Controller Performance

The PID controller is implemented within the LabVIEW environment, as shown in Figure 3. The PID parameters obtained from Equation (21) are substituted into the transfer function of the Ball and Beam system described in Equation (8). Using these parameters, the closed-loop system response is evaluated. The resulting dynamic response, presented in Figure 4, demonstrates the effectiveness of the selected PID controller in improving system stability and achieving the desired control performance.

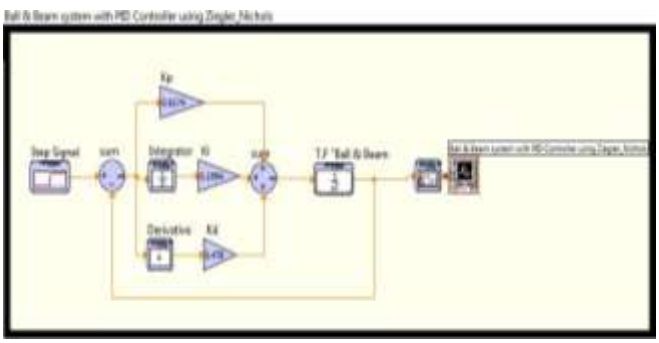


FIGURE 6. LabVIEW simulation of the Ball and Beam system with PID controller.

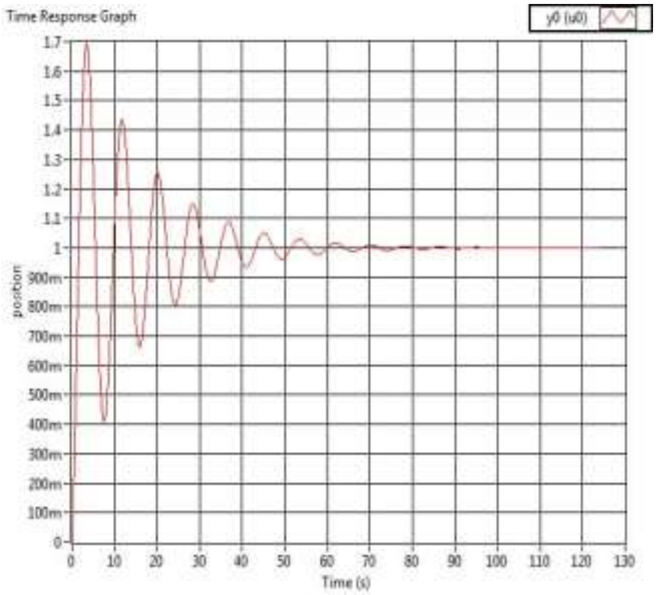


FIGURE 7. Dynamic response of the Ball and Beam system with PID controller.

### *A.2 Tyreus_Luyben PID Controller*

By substituting the ultimate gain $ku$ and ultimate period $p_u$, the PID controller parameters in equation 9 are determined.

$$k_P = k_c = 0 \cdot 46768 \qquad (22)$$

$$k_i = \frac{k_c}{Ti} = 0.03432 \qquad (23)$$

$$k_D = kT_d = 0.45981 \qquad (24)$$

$$G_c(s) = 0 \cdot 46768 + \frac{0.03432}{s} + 0.45981s \quad (25)$$

TABLE III
CONTROLLER PARAMETERS IN THE TYREUS–LUYBEN CLOSED-LOOP METHOD [6]

| | $k_c$ | $T_i$ | $T_d$ |
|---|---|---|---|
| PID controller | $\frac{k_u}{2.2}$ | $2.2pu$ | $\frac{Pu}{6.3}$ |
| Value | 0.46768 | 13.6268 | 0.98317 |

#### *A.2.1* LabVIEW-Based Analysis of PID Controller Performance

The PID controller is implemented within the LabVIEW environment, as shown in Figure 5. The PID parameters obtained from Equation (25) are substituted into the transfer function of the Ball and Beam system described in Equation (8). Using these parameters, the closed-loop system response is evaluated. The resulting dynamic response, presented in Figure 6, demonstrates the effectiveness of the selected PID controller in improving system stability and achieving the desired control performance.

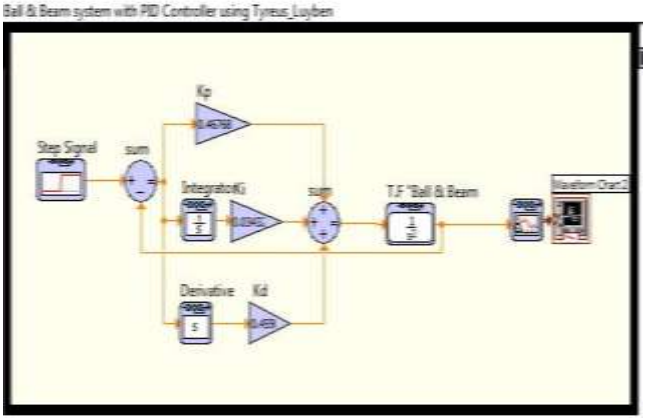


FIGURE 8. **LabVIEW simulation of the Ball and Beam system with PID controller.**

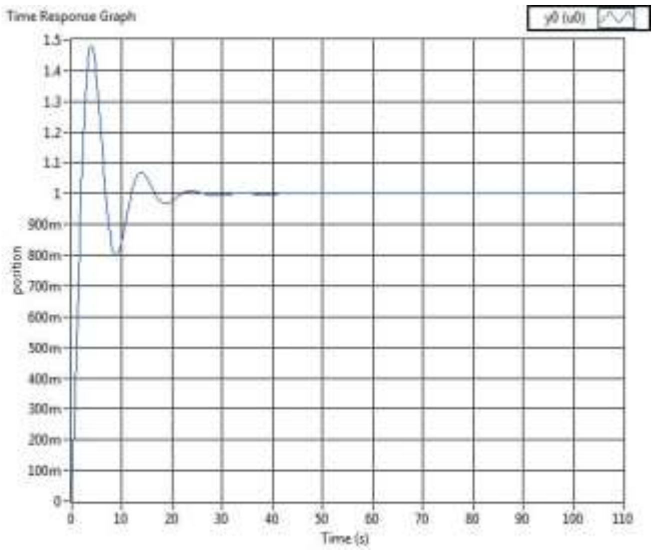


FIGURE 9. **Dynamic response of the Ball and Beam system with PID controller.**

## *B. IMC-Based PID Controller*

Internal Model Control (IMC) is a control design methodology that incorporates an internal model of the system within the controller structure. This allows the controller to predict and anticipate the system's response, providing robust and accurate control against disturbances and model uncertainties.

IMC-Based PID controllers combine the predictive capabilities of IMC with the simplicity and widespread applicability of conventional PID control. Using this approach, PID parameters (Kp, Ki, Kd) can be derived analytically from the IMC design, eliminating the need for trial-and-error tuning .[10]

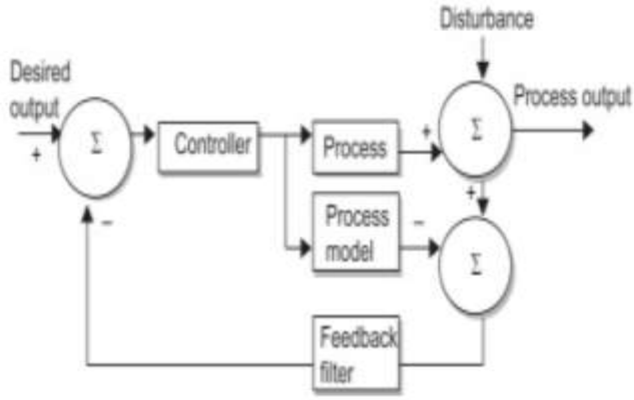


FIGURE 10. **Block Diagram of Internal Model Control (IMC)**

**Design procedure:**

**1-System modeling (G(s))**: Develop an accurate mathematical representation of the system to be controlled, as represented in Equation 8.

**2-IMC filter design (λ)**: Introduce a low-pass filter to control response speed and reduce sensitivity to measurement noise.

$$Gf(s) = \frac{1}{(\lambda s + 1)^n} \tag{27}$$

$$Gf(s) = \frac{1}{(s + 1)^2} \tag{28}$$

where $n$ is sufficiently large to ensure that the **internal model controller** Q(s) **is proper**. The parameter λ represents the **filter time constant**, which is determined based on the desired system performance.

- A smaller λ results in a faster closed-loop response**.**
- A larger λ makes the system less sensitive to model uncertainties or mismatches**.[**11]

**3-IMC Transfer Function:** The internal model controller Q(s) is defined as the ratio of the IMC filter f(s)to the process model G(s):[11]

$$Q(s) = \frac{Gf(s)}{Gp(s)} \tag{29}$$

$$Q(s) = \frac{s^2}{1.029(s + 1)^2} \tag{30}$$

**4-PID Parameter Derivation:** The PID gains KP, KI, and KD are directly extracted from the IMC structure using the filter time constant λ, linking the controller's performance to the system dynamics.[11]

$$G_C(s) = \frac{Q(s)}{1 - Gp(s)Q(s)} \tag{29}$$

$$G_C(s) = \frac{s}{1.029(s+2)} \tag{30}$$

**5-Performance Evaluation:** Assess the closed-loop stability, reference tracking capability, and disturbance rejection of the system.

### *B.1* LabVIEW-Based Analysis of IMC_ based PID Controller Performance

The IMC-based PID controller is implemented in the LabVIEW environment, as shown in Figure 8. The PID parameters obtained from the IMC design procedure are applied to the transfer function of the Ball and Beam system described in Equation (30). Using these parameters, the closed-loop system response is evaluated. The resulting dynamic response, presented in Figure 9, demonstrates the effectiveness of the IMC-based PID controller in enhancing system stability and achieving the desired control performance.

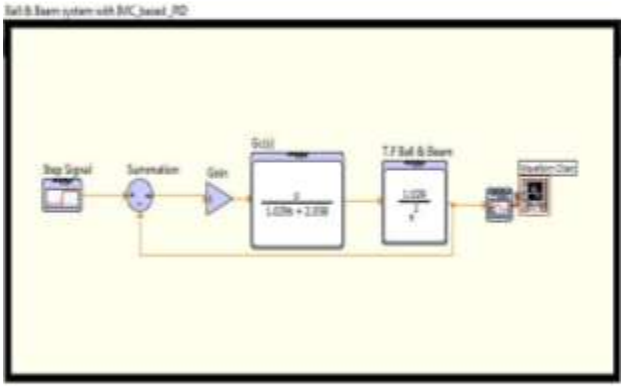

FIGURE 11. **LabVIEW simulation of the Ball and Beam system with IMC _Based_PID controller.**

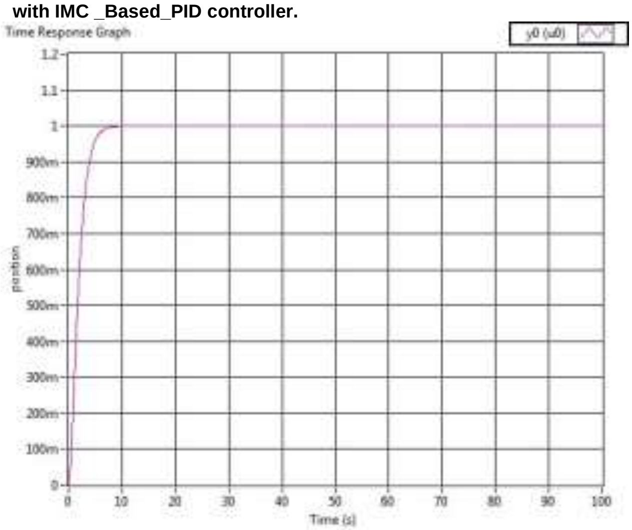


FIGURE 12. **Dynamic response of the Ball and Beam system with IMC based PID controller.**

To evaluate the robustness of the IMC-based PID controller, the system is subjected to a disturbance in the form of a step input of magnitude 0.2 at time 10 sec. The resulting effect on the closed-loop response is observed, and the procedure is implemented in LabVIEW using a block diagram to simulate the disturbance and record the system response.

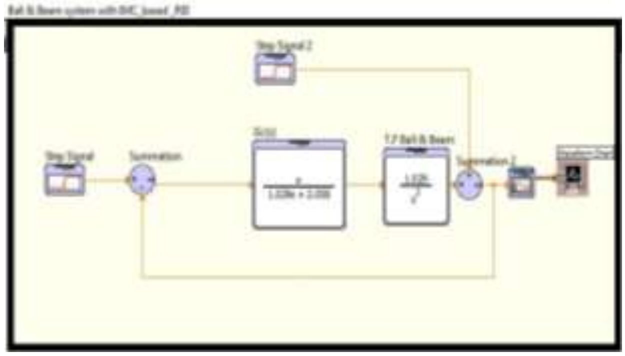

FIGURE 13. **Effect of a step disturbance on the IMC-based PID controlled system**

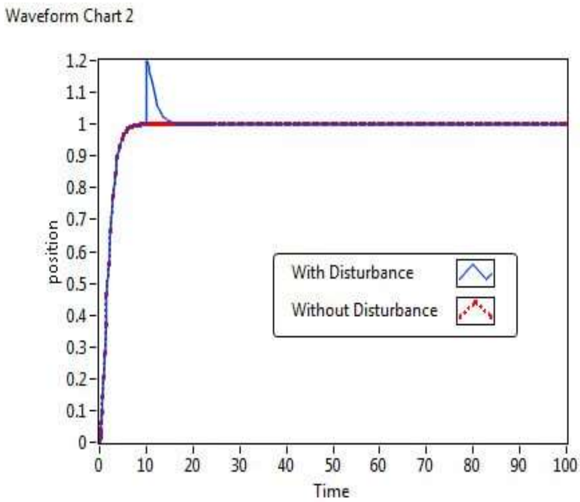


FIGURE 14. **Closed-loop response of the system under a step disturbance**

### C. *Fuzzy Logic Control*

The Ball & Beam system is a nonlinear and complex system, where the position of a ball rolling on a beam is controlled by adjusting the beam's tilt angle via a motor. Controlling this system is highly challenging due to its instability and nonlinearity, making conventional control methods such as PID dependent on complex mathematical modeling. Therefore, Fuzzy Logic Control (FLC) is employed as an effective solution for controlling the Ball & Beam system. Fuzzy control does not require an accurate mathematical model of the system; instead, it relies on linguistic logical rules that mimic human reasoning and can handle imprecise and uncertain inputs. For this reason, fuzzy control is particularly suitable for controlling nonlinear systems like the Ball & Beam.[12]

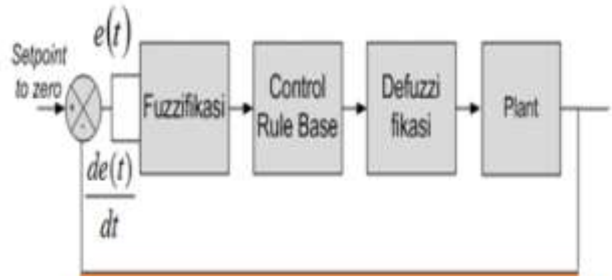


**FIGURE 15.** **Structure of Fuzzy logic control**

In this work, a two-input, single-output (MISO) fuzzy logic controller was employed for automatic system control. The inputs to the fuzzy controller are the error signal (Error) and the rate of change of error (ΔError)**,** where the error represents the difference between the desired and current system values, and ΔError represents the change between the current and previous error values. This approach is used to reduce instability and improve the response of nonlinear systems, such as the Ball & Beam system.[13]

To implement this algorithm, the input signals were divided over their full range using membership functions. Fig.13 shows the membership function for the error with a range from -40 to 40. This range is divided into seven membership functions, each corresponding to a specific linguistic variable. The membership functions are defined as Negative Large (NL), Negative Medium (NM), Negative Small (NS), Zero, Positive Small (PS), Positive Medium (PM), and Positive Large (PL).[5]

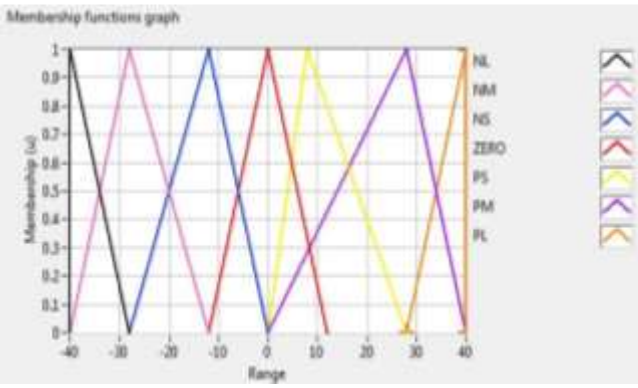


**FIGURE 16.** **Membership position error.**

The membership functions for the Position Error Rate were designed to have a smaller range from -20 to 20. This range was chosen to reduce disturbances that mostly occur during the ball positioning control. Fig.14, shows the membership functions for the Position Error Rate.[5]

The output of the controller is shown in Fig.15, which represents the membership function of the controller output**.** The range was normalized within -1 to 1, and then scaled to the actual output range of the fuzzy controller. In this study, 7 membership functions were created. However, the number of membership functions can be increased if higher resolution is desired.[5]

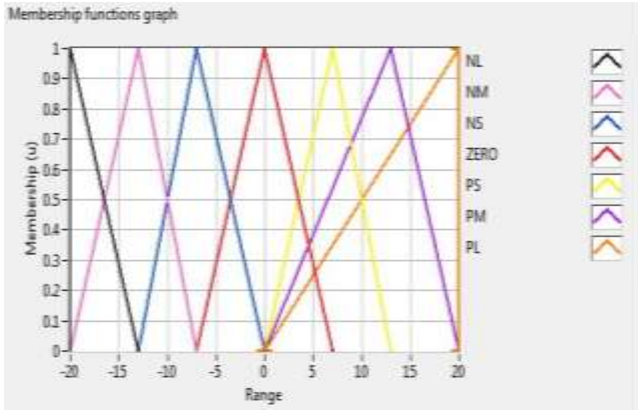


**FIGURE 17.** **Membership Position Error Rate .**

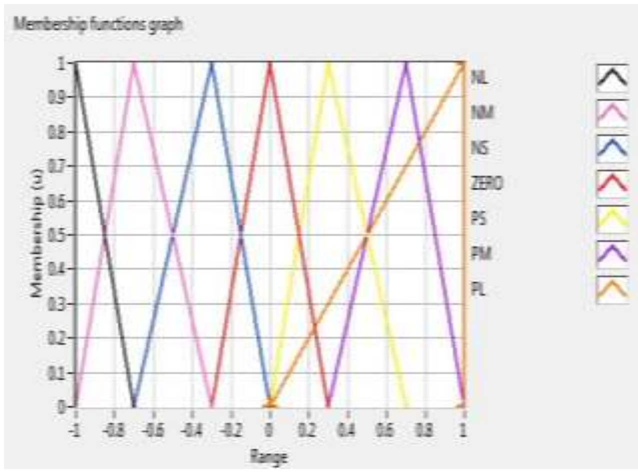


**FIGURE 18.** **Membership function (output).**

The output of the fuzzy logic controller was determined using if–then rules that map input-output relationships. These rules are generally formulated based on human logical reasoning regarding the problem and its solution. For example: *“If the error e is large and the change in error Δe is large, then the output is large.”* In this study, fuzzy rules were systematically generated from an input-output map (Table IV), resulting in 49 fuzzy rules corresponding to 7 membership functions for each input variable.

### *1. LabVIEW-Based Analysis of Fuzzy Logic Controller Performance*

The fuzzy logic controller was implemented in the LabVIEW environment, as illustrated in Figure 16. The controller utilizes fuzzy rules and membership functions, which were designed based on the input-output mapping of the Ball and Beam system (Equation 8), to regulate the system. Using this controller, the closed-loop system response was evaluated. The resulting dynamic response, shown in Figure 17, demonstrates the effectiveness of the fuzzy logic controller in improving system stability and achieving the desired control performance.

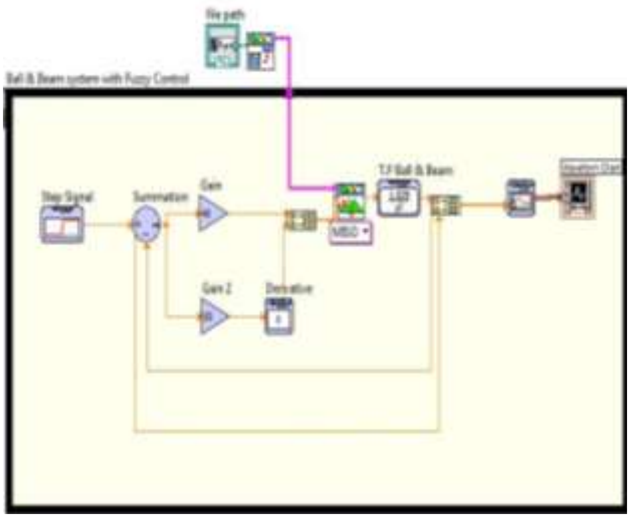


**FIGURE 19.** **LabVIEW simulation of the Ball and Beam system with Fuzzy logic controller.**

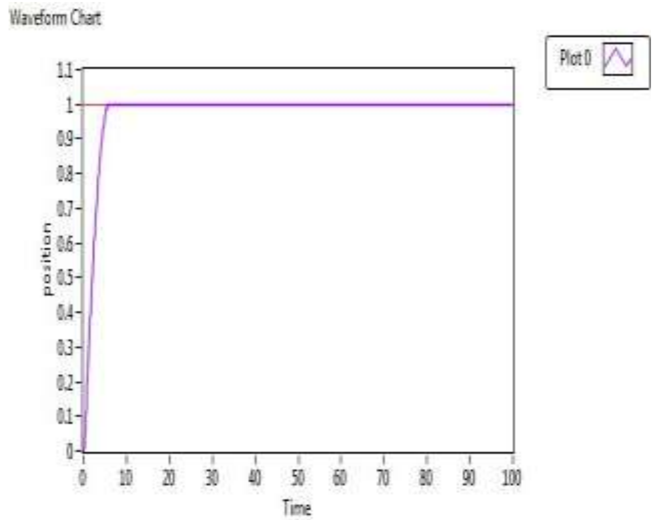


**FIGURE 20.** **Dynamic response of the Ball and Beam system with Fuzzy logic controller.**

TABLE IV
FUZZY RULES

| Position Error Rate $\Delta e$ | Position error $e$ | | | | | | |
|---|---|---|---|---|---|---|---|
| | PL | PM | PS | ZERO | NS | NM | NL |
| NL | ZERO | NS | NM | NL | NL | NL | NL |
| NM | PS | ZERO | NS | NM | NL | NL | NL |
| NS | PM | PS | ZERO | NS | NM | NL | NL |
| ZERO | PL | PM | PS | ZERO | NS | NM | NL |
| PS | PL | PL | PM | PS | ZERO | NS | NM |
| PM | PL | PL | PL | PM | PS | ZERO | NS |
| PL | PL | PL | PL | PL | PM | PS | ZERO |

## IV. Performance Comparison and Discussion

The performance of the proposed control strategies was evaluated through real-time simulations using the LabVIEW environment. A quantitative comparison was conducted using standard performance indices, including rise time (Tr), peak time (Tp), settling time (Ts), percentage overshoot (OS%), steady-state error (ess), and the system's robustness to external disturbances.

The Ziegler–Nichols PID controller exhibited a fast initial response; however, it suffered from a significant overshoot of approximately 69.77% and an excessively long settling time exceeding 70 seconds. This behavior is consistent with the characteristics of the Ziegler–Nichols tuning method, which prioritizes rapid response at the expense of oscillatory behavior, making it less suitable for inherently unstable systems such as the Ball and Beam.

The Tyreus–Luyben PID controller improved system performance compared to the Ziegler–Nichols method. The overshoot was reduced to approximately 48.14%, and the settling time decreased to around 21.15 seconds. These improvements indicate better damping and enhanced stability. However, some oscillations remain, and the response is still relatively slow for precision control applications.

The IMC-based PID controller provided the best overall performance among the PID-based methods. Simulation results showed zero overshoot, a very short settling time of approximately 6.6 seconds, and excellent disturbance rejection capability. When the system was subjected to an external step disturbance, it quickly returned to the desired equilibrium without sustained oscillations, confirming the robustness of this approach and its effectiveness in handling model uncertainties.

TABLE V
SYSTEM DYNAMIC RESPONSE PARAMETERS UNDER VARIOUS CONTROL METHODS.

| Performance specification | System with Z_N PID | system with T_L PID | System with IMC based PID |
|---|---|---|---|
| Settling Time $T_s$ | 70.0546 sec | 21.15 sec | 6.6 sec |
| Peak Time $T_P$ | 3.44966 sec | 3.78806 sec | 8 sec |
| Rise Time $T_r$ | 1.32679sec | 1.57836 sec | 3.4 sec |
| Overshoot (OS%) | 69.7705 % | 48.1393 % | 0 % |
| Error ($e_{ss}$) | 0 | 0 | 0 |

The Fuzzy Logic Controller (FLC) demonstrated stable and smooth system behavior without requiring an explicit mathematical model. Its response featured reduced oscillations and acceptable transient performance, making it particularly suitable for nonlinear systems. Although the tuning of the fuzzy controller relies on expert knowledge and rule design, it showed strong potential for real-time and adaptive control applications.

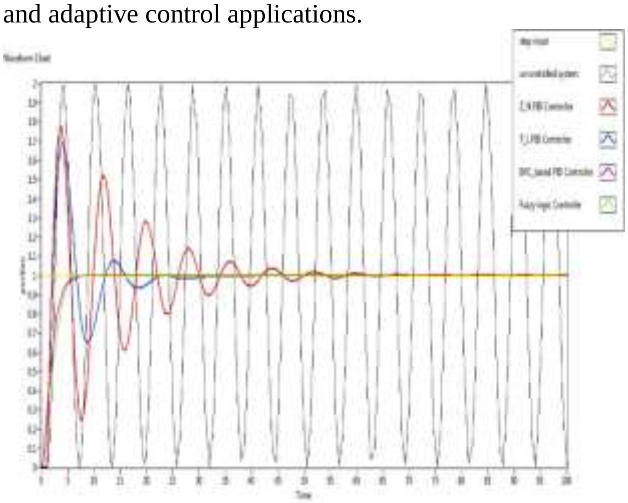

**FIGURE 21.** **Closed-Loop Responses under Various Control Methods.**

Overall, the comparative analysis highlights that the IMC-PID controller provides the most balanced performance in terms of stability, speed, and robustness, while fuzzy logic control offers a flexible and effective alternative for controlling nonlinear systems.

## V. CONCLUSION

This paper presented a comprehensive analysis and comparative study of four control strategies applied to the Ball and Beam system using the LabVIEW simulation environment. The system was modeled, linearized, and controlled using the Ziegler–Nichols PID, Tyreus–Luyben PID, IMC-based PID, and Fuzzy Logic controllers. Simulation results demonstrated that conventional PID controllers are capable of stabilizing the system, but they often exhibit high overshoot and long settling times, particularly when tuned using the Ziegler–Nichols method. The Tyreus–Luyben approach improved damping and reduced oscillations; however, its performance remains limited for applications requiring high precision.

The IMC-based PID controller achieved the best overall performance, characterized by zero overshoot, fast settling time, and strong robustness against disturbances. Similarly, the Fuzzy Logic controller provided effective stabilization and smooth system response, confirming its suitability for nonlinear and uncertain systems.

Future work may include experimental validation using real-time hardware implementations, the development of adaptive or self-tuning PID–Fuzzy hybrid controllers, and the application of optimization-based tuning techniques to further enhance system robustness and performance under varying operating conditions. Such advancements have the potential to provide more efficient and reliable control solutions for unstable and nonlinear systems, such as the Ball and Beam.

## REFERENCES

[1] Z. Shareef, *A Simplified Intelligent Controller for Ball and Beam System*, 2010 IEEE 2nd ICETC.

[2] Bansode Lawrence, *Tuning of a PID Controller for Optimal Performance of Ball and Beam System*, IJERT, Vol. 9, Issue 04, April 2020.

[3] Wen Yu, *Stability Analysis of PD Regulation for Ball and Beam System*, 1999.

[4] A. Taifour Ali et al., *Design and Implementation of Ball and Beam System Using PID Controller*, Sudan University of Science and Technology.

[5] Minh Vu et al., *Evaluation of Fuzzy PID Controller in Ball and Beam System*, 2017 IEEE.

[6] Narong Aphiratsakun & Nane Otaryan, *Ball On The Plate Model Based on PID Tuning Methods*, Assumption University of Thailand.

[7] Emhemed, A. A. A. (2013). Fuzzy control for nonlinear Ball and Beam system. *International*R. Nicole, "Title of paper with only first word capitalized," J. Name Stand. Abbrev., in press.

[8] B. Ahmad and I. Hussain, "Design and hardware implementation of ball & beam setup," in *Proc. 2017 Fifth International Conference on Aerospace Science & Engineering (ICASE)*, Islamabad, Pakistan, 2017, pp. 1–6, doi: 10.1109/ICASE.2017.8374271.

[9] Norman S. Nise. Control Systems Engineering. 6th ed., New York: John Wiley & Sons, 2010

[10] ScienceDirect. (n.d.). *Internal Model Control*. Retrieved January 5, 2026, from

[11] Z. Zhao, Z. Liu, and J. Zhang, “IMC-PID tuning method based on sensitivity specification for process with time-delay,” *J. Cent. South Univ. Technol.*, vol. 18, pp. 1153–1160, 2011, doi: 10.1007/s11771-011-0817-0.

[12] Moezzi, S., et al. (2018). Fuzzy Logic Control for a Ball and Beam System. *International Journal of Innovative Technology and Interdisciplinary Sciences (IJITIS), 1*(1), 39–48.

[13] M. Martin, D. B. Margana, and E. Habinuddin, "Fuzzy Logic Controller Implementation for Motor DC Control Position With Real-Time Operating System," *Politeknik Negeri Bandung, Jawa Barat, Indonesia*, 2023.