Comparative insights into nonlinear PID-based controller design approaches for industrial applications

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ABSTRACT

Proportional-integral-derivative (PID) controllers are established in manufacturing due to their simple design, robustness, and wide-ranging industrial applications. However, traditional PID controllers often struggle with the complexity and nonlinearity behaviors inherent in many control systems. As a result, ongoing and future research is focused on developing more stable PID controllers that function efficiently without heavily depending on exact mathematical models, by fine-tuning controller parameters. This study explores several PID-based controllers, including non-linear PID (N-PID), multi-rate non-linear PID (MN-PID), and self-regulating nonlinear PID (SN-PID), assessing and contrasting their performance. The efficacy and robustness of these control mechanisms are substantiated through comparative analyses with the sliding mode control technique, employing experimental data from a pneumatic actuator system to assess performance across varying load scenarios. SN-PID outperforms sliding mode controller (SMC) by 90.97% and PID by 89.90%, followed by MN-PID (85.58% over SMC, 83.86% over PID) and N-PID (78.08% over SMC, 75.49% over PID), while PID offers only 10.63% improvement over SMC. These findings provide valuable insights and recommendations for enhancing controller performance. These insights aim to guide control engineers in selecting the most appropriate N-PID design strategy for specific applications, ultimately improving system performance and operational efficiency in industrial environments.

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1. INTRODUCTION

In the field of industrial control systems, proportional-integral-derivative (PID) controllers have long been recognized for their stability and efficiency, consistently proving reliable across numerous industrial sectors [1]–[8]. Their popularity in industrial use is owed to their simplicity and effectiveness. However, traditional ways of designing PIDs may not always deliver the best outputs, especially when a complex non-linear system is involved [9]–[14]. PID controllers need improvement to sustain their robustness under dynamic conditions as industrial automation advances rapidly. This was highlighted by the research works of [15]–[21] As indicated in [22]–[24], recent studies have shown how important PI-based controllers are in dealing with disturbances, parameter uncertainties, and inherent nonlinearities encountered in a wide range of industrial processes, thus enhancing their efficiency and reliability.

Adaptive practices are now a reality in PID controllers. Developments in control theory have facilitated the incorporation of adaptability in PID controllers and improved their resilience and flexibility within complex industrial settings [25], [26]. They provide for adapting their parameters in real-time based on the available data to enhance performance across various operating conditions and disturbances. The use of such advanced techniques is yet another proof of the continued efforts being made to enhance industrial processes through better PID control. These attempts still underline how significant PID controllers remain in contemporary industrial processes. Different research works [27], [28] also proposed a new design approach for PID controllers by incorporating non-linear functions with more sophisticated optimization algorithms to improve disturbance response performance. They proposed a nonlinear PID (N-PID) controller with variable gains as well as a filter within a parallel linear framework having one single nonlinear function simplifying tuning for P and D actions. The integral of time-weighted absolute error was used to minimize the parameters tuning in the real-coded genetic algorithm (RCGA), including population initialization, fitness evaluation, reproduction, crossover, and mutation. This controller demonstrated better disturbance handling and performance stability compared to traditional controllers like Rao-DS, Sk-DS, and Luyben-SA when tested on pure integrating process with time delay (PIPTD) and integrating first order process with time delay IFOPTD processes. Moreover, a basic nonlinear function adjusting online gains and a lead-lag compensator with noise suppression capacity were included in the N-PID controller to improve its robustness under dynamic situations.

Advancements in machine learning techniques have also played a major role in recent improvements to PID controllers. This evolution of PID controllers' abilities to adjust themselves and self-regulate led to their overall efficiency improving across various operational scenarios [29]–[37]. By employing different machine learning techniques such as artificial neural networks and reinforcement learning algorithms, PID controllers can now be self-tuned using real-time data inputs, making them more robust against disturbances and uncertainties experienced in industries. With the integration of these machine learning principles into control systems, the design philosophy has shifted from traditional ways that sought high efficiency and adaptability toward dynamic industrial landscapes.

In other research, it has been pointed out that there were possibilities to improve the performance of PID controllers through advanced tuning methods, as shown in [38]–[41]. The researchers have included techniques such as model predictive control (MPC) and intelligent optimization algorithms for enhancing the robustness and adaptability of PID controllers in various industrial applications. In these approaches, computational advances are exploited alongside real-time data analytics to fine-tune controller parameters contributing to efficient and effective industrial automation. A recent study introduced a novel nonlinear PID (NLPID) control algorithm that improved simultaneous set-point tracking and disturbance rejection for controlling nonlinear systems [42]. MATLAB/Simulink was used to compare the NLPID controller's performance with established controllers like conventional PID, two-degree-of-freedom PID, and Smith Predictor PID controllers for a FOPTD system with different uncertainties and disturbances. It is evident from the findings that the NLPID controller has faster settling time/Rise time compared to conventional PID, two degrees of freedom PID, and Smith predictor PID; better disturbance rejection and robust stability/speed; shows resilience against parametric/additive/multiplicative uncertainty.

In a different application discussed in [43], improvements in control methodologies for grid-connected photovoltaic (PV) systems have underscored the efficacy of the N-PID controller, which is based on Popov's stability criterion. This new concept introduces a nonlinear gain, thus leading to the creation of a nonlinear relationship with the error signal, which enhances reference tracking accuracy as well as simplifies the often difficult calibration process of standard PID controllers. The N-PID controller is very good at regulating the duty cycle of the DC-AC converter to extract maximum power and prevent harmonic distortion while at unity power factor, maintaining system efficiency within the 96% to 99% range. Simulations have repeatedly shown that the N-PID controller outperforms conventional PID controllers in maximum power point tracking (MPPT) by reducing oscillations, achieving quicker convergence, and keeping total harmonic distortion (THD) below 0.5%. In other previous research conducted by Muthukumari *et al*. [44], a smart-tuned PID controller based on the single-ended primary inductor converter (SEPIC) was proposed for detecting the MPPT in a wind energy conversion system (WECS). This study aimed to manage voltage and frequency variations from a permanent magnet synchronous generator (PMSG) due to changes in wind speed, using the smart SEPIC to maintain a stable DC link voltage. A variable-speed 1.5 MW WECS with an AC-DC-AC converter was developed using MATLAB/Simulink and tested with the DSP processor MSP430F5529. Results from both simulations and experiments demonstrated that this method outperforms conventional PID controllers in terms of power quality, confirming the performance improvement of the smart tuning approach.

Additionally, the N-PID controller has undergone extensive study in its application in highly nonlinear systems, as evidenced by research investigations in [24] and [45]–[50]. This implies that developing PID-based control strategies further and incorporating adaptive functions for parameter variations of the main controller may result in great advantages. In this journal paper, several approaches based on this idea have been reviewed and compared to determine their efficiency and benefits. To look into possible improvements of these control methods, a similar plant, that is a pneumatic actuator, is used for evaluation purposes, with standard experiments and analyses being performed on each technique.

This article is arranged as follows: It begins with an Introduction outlining the research objectives. The Method section describes the refinement of the PID controller, followed by the development of advanced controllers: N-PID, multi-rate nonlinear PID (MN-PID), and self-regulation nonlinear PID (SN-PID). The Results and Discussion evaluate the controllers' performance, including a quantitative performance comparison and an analysis of their robustness under varying load conditions. The findings highlight the effectiveness of the proposed methods in improving system control. Finally, the conclusion summarizes the key insights and provides recommendations for enhancing industrial control strategies.

2. METHOD

This section presents a method for enhancing the performance of the PID controller, beginning with the improvement of the conventional PID controller as the baseline. Next, the N-PID controller is introduced to handle nonlinearity, followed by the MN-PID controller, designed to manage systems with varying gain values. Finally, the SN-PID controller is developed to adjust its parameters automatically for better adaptability.

2.1. Refinement of PID controller

The classical PID controller is widely recognized for its straightforward design, enabling efficient management of position and motion control. However, it often struggles to achieve optimal performance in challenging position control applications, particularly those involving significant nonlinearities. To address these limitations, enhanced versions of the PID controller that incorporate nonlinear gain can be investigated. This study examines previous research on the integration of nonlinear gain with PID-based controllers, specifically applied to industrial pneumatic actuators. The analysis includes a comparative evaluation of various PID-based strategies, namely N-PID, MN-PID, and SN-PID controllers. The performance of these strategies is assessed to determine which modifications offer substantial improvements in both transient and steady-state performance. Furthermore, the robustness of these controllers is evaluated by comparing their performance with that of the sliding mode controller (SMC), providing a comprehensive assessment of their effectiveness.

2.2. N-PID controller

The N-PID controller in this study is structured such that it incorporates a sector-bounded nonlinear gain, $k(e)$, which operates in cascade with a PID controller. The automatic gain, $k(e)$, functions as a nonlinear dependency on the error, $e(t)$, confined within the sector $0 \leq k(e) \leq kmax$ as defined in (1) and (2). These equations outline the permissible range for the nonlinear gain, $k(e)$. The parameter α represents the variation rate of the nonlinear gain, while e_{max} defines its range of variation. The selection of parameters α and e_{max} depends on the maximum allowable value of the nonlinear gain $k(e)$, which is determined based on the gain range required for stability. The resulting output from this nonlinear function is termed the scaled error and is represented in (3), while the complete equation for the N-PID controller is provided in (4).

$$k(e) = \frac{\exp(\alpha e)+\exp(-\alpha e)}{2} \qquad (1)$$

$$e = \begin{cases} e & |e| \leq e_{max} \\ e_{max} sign(e) & |e| > e_{max} \end{cases}$$

$$k(e_{max}) = -\frac{1}{|G(j\omega)|} \qquad (2)$$

$$f(e) = k(e).e(t) \qquad (3)$$

$$f(e).u_{PID} = k_P[k(e).e(t)] + \frac{k_p}{T_I}\int_0^t [k(e).e(t)]\,dt + k_p T_d \frac{d}{dt}[k(e).e(t)] \qquad (4)$$

2.3. MN-PID controller

The MN-PID controller is an approach designed to enhance the NPID controller. This controller incorporates several sector-bounded nonlinear gains, $k(e, \alpha_x)$, designed to tune the parameter α to create multiple gain sectors, known as the multi-rate function, as illustrated in Figure 1. These bounded sectors are automatically chosen to enhance the controller's adaptability, allowing for a broad spectrum of gain tuning. The implementation hinges on selecting α_x, influenced by factors such as friction, load variations, and the discrepancy between the reference and actual values of the controlled variable. The selection of α_x generates various ranges for the nonlinear gain, $k(e, \alpha_x)$. For each initial movement, a higher value of nonlinear gain, $k(e, \alpha_x)$ should be selected to provide sufficient force for friction compensation.

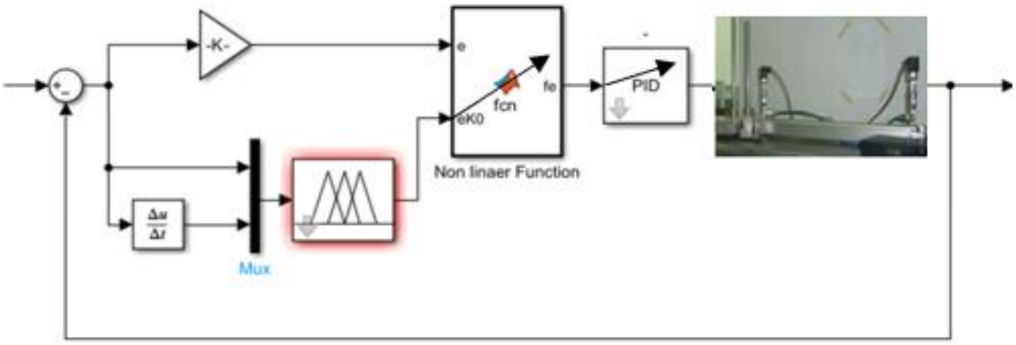

Figure 1. System with MN-PID controller

The multi-rate nonlinear function's behavior is contingent upon the characteristics of the nonlinear gain as α varies, as shown in Figure 2. It is observed that for any value of α, the nonlinear gain $kx(e)$ equals one when the error $e = 0$. In this situation, the MN-PID controller effectively operates as a conventional PID controller.

Let $\theta = [K_P, K_i, K]$ and $\xi(t) = \left[e(t), \int_0^t e(\tau)d\tau, \frac{d}{dt}e(t)\right]^T$. Thus, the MN-PID equation is (5).

$$u_{MN-PID}(\theta, e) = K_x(e, \alpha_x).\theta\xi(t) \quad (5)$$

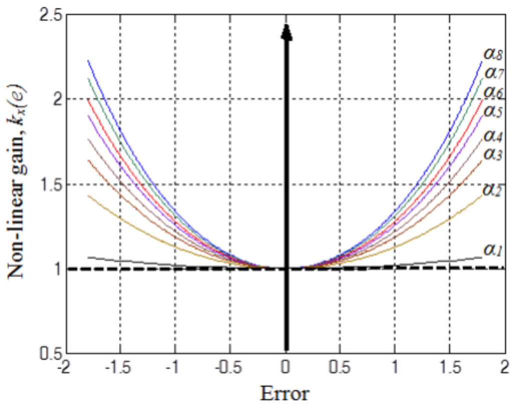

Figure 2. Nonlinear gain profiles as a function of α

As depicted in Figure 2, the value of α produced by the fuzzy logic technique may either increase the parameters θ or remain unchanged. The nonlinear gain $kx(e, \alpha_x)$ is defined as a multi-rate nonlinear function of error, where the specific rule is determined by the selection of α_x within the range $1 \leq kx(e, \alpha_x) \leq kx(e_{max}, \alpha_x)$. The surface plot of the nonlinear gain variation rate according to the fuzzy logic tuning rules is shown in Figure 3. The final output of the fuzzy system is provided in (6).

$$\alpha_x(z) = \frac{\sum_{j=1}^{N} \mu_j(z)\alpha_j}{\sum_{j=1}^{N} \mu_j(z)} \quad (6)$$

The rules governing the nonlinear function of the MN-PID controller are as:

$$IF|e(kT)|\ is < linguistic\ label > AND\ \Delta|e(kT)| < linguistic\ label > THEN\ \alpha_x$$

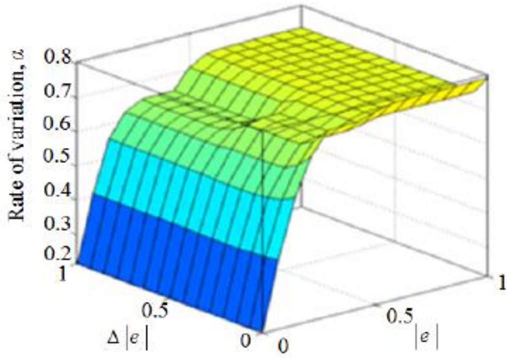

Figure. 3. Surface plot of nonlinear gain variation rate

2.4. SN-PID controller

This technique enhances the N-PID controller by aligning its design objective with that of the MN-PID controller but without utilizing fuzzy logic to determine the rate variation, α, of the nonlinear gain. Instead, it addresses the challenge of identifying suitable rules for the fuzzy tuning mechanism in the MN-PID by directly generating the value of α through a predefined function; see (6). This approach results in a more adaptable controller. The self-regulation nonlinear function (SNF) stands out for its simplicity and minimal need for additional computation time. Due to its rapid execution time and effectiveness in achieving performance levels unattainable by both conventional PID and nonlinear PID controllers, this technique is well-suited for industrial applications. Determining the optimal value of α for superior performance in terms of speed and chattering avoidance is challenging. This method enables the value of α to be generated dynamically in real-time to enhance the controller's flexibility. Figure 4 illustrates the block diagram of this method. The nonlinear gain $kx(e)$ is automatically adjusted based on the value of α_i, which is directly generated using the SNF equation as defined in (7).

$$\frac{\alpha_i(s)}{e(s)} = \frac{d}{ds}\left|\frac{\delta}{\beta s+1}\right| \tag{7}$$

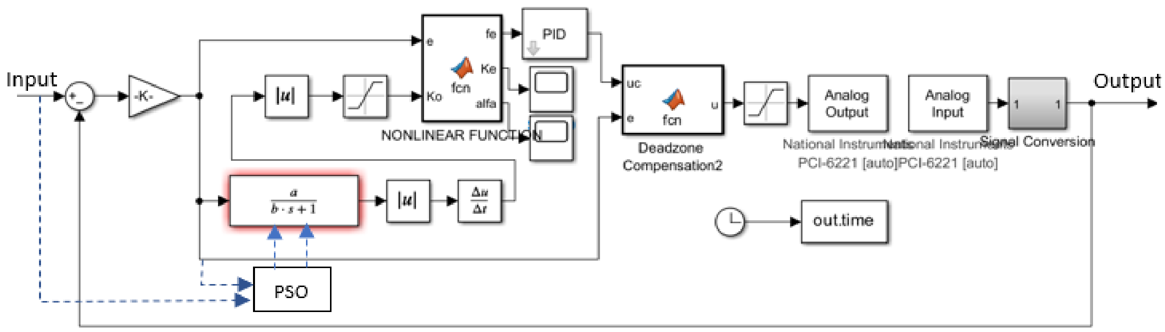

Figure 4. Block diagram of SN-PID controller

To automatically generate α, the relationship between δ and β is determined in advance. A particle swarm optimization (PSO) technique is employed to identify this relationship. This technique begins with a set of randomly generated solutions (particles) and seeks optimal solutions by iteratively updating generations. Each particle, representing a candidate solution in the initial stages, is assigned a specific fitness value. The particles move with a velocity influenced by their own experiences and those of others. Throughout this process, the velocity and position of each particle are updated based on two key values: The Personal Best (P_{best}) and the global best (G_{best}) solutions. The velocity and position of each particle can be calculated using the current velocity and the distance from P_{best} to G_{best}, as detailed in (8) and (9), respectively.

$$V_i^{t+1} = w.V_i^t + c_1.rand_1(.).(Pbest_i - X_i^t) + c_2.rand_2(.).(Gbest_i - X_i^t) \quad (8)$$

$$X_i^{t+1} = X_i^t + V_i^{t+1} \quad (9)$$

The value of w is set by (8) as

$$w = w_{max} - \frac{w_{max} - w_{min}}{itr_{max}} \times itr \quad (10)$$

where
w : inertia weight function
c_1 & c_2 : learning factor
$rand_1$ & $rand_2$: random numbers in range [0,1]
itr_{max} : maximum number of iterations
itr : current iteration
$i = 1,2,3,4, \dots \dots, N_{swarm}$

The performance criterion in the time domain as described in (11) is employed for this optimization. This criterion is employed to compute the cost function for evaluating the parameters of the SNF. It considers various output response constraints, such as overshoot, rise time, settling time, and steady-state error. The cost function f is defined as the reciprocal of the performance criterion W(K), as outlined in (12).

$$W(K) = (M_P + e_{ss}).(1 - e^{-\sigma}) + (t_S - t_r).e^{-\sigma} \quad (11)$$

$$f = \frac{1}{W(K)} \quad (12)$$

Here, K is $[\delta, \beta]$ and σ is the weighting factor.

3. RESULTS AND DISCUSSION

3.1. Performance comparison of various control methods

Figure 5 shows the closed-loop responses of the system under different controllers. Qualitative analysis indicates that the MN-PID and SN-PID controllers achieve the best performance. The transient response of the system controlled by the SMC is similar to these methods. However, in steady-state conditions, as shown in the zoomed-in view, the SN-PID controller outperforms the others. The N-PID controller exhibits the poorest performance in terms of speed. Nonetheless, its steady-state performance is comparable to that of the SN-PID controller. The conventional PID controller provides a fast response. However, this rapid response is accompanied by a significant overshoot, where the system output exceeds the desired setpoint before stabilizing. This overshoot indicates a lack of robustness in the system, as it may lead to instability or undesirable oscillations. The presence of overshoot and the subsequent settling time needed to stabilize the system diminishes the overall performance of the conventional PID controller compared to the advanced methods.

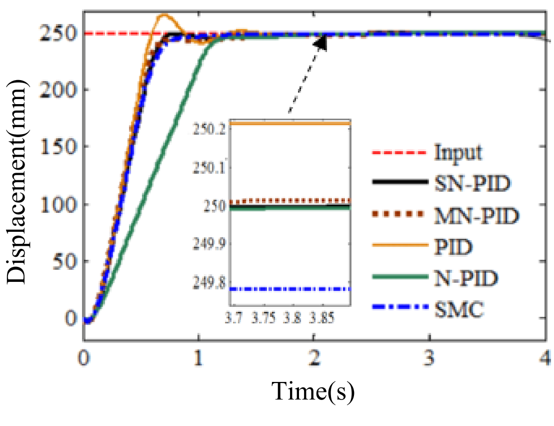

Figure 5. Dynamic performance comparison of different control strategies

3.1.1 Quantitative performance evaluation

The integrated absolute error (IAE), as defined in (13), is employed to quantitatively evaluate the performance of the different controllers. The IAE is a widely used performance metric in control systems, representing the accumulated absolute error over time. Lower IAE values indicate better performance as they reflect smaller deviations from the desired setpoint. Each control method is tested on a system operating for 4 seconds with a target distance of 250 mm. This setup provides a consistent and controlled environment for assessing the accuracy and effectiveness of each controller over a significant duration.

$$IAE = \int_0^{\infty} |r(t) - y(t)| dt \tag{13}$$

Figure 6 presents the performance results based on the IAE metric, from which several key observations can be made. The SN-PID and MN-PID controllers exhibit the lowest IAE values, clearly outperforming the other techniques. These controllers effectively minimize the absolute error over the testing period, demonstrating their superior ability to maintain the system at the desired setpoint with high precision. The N-PID controller also shows good performance, with relatively low IAE compared to the conventional PID and SMC. Despite its sluggish transient response, which indicates a slower reaction to changes, the N-PID controller manages to achieve a steady-state performance close to the SN-PID controller. This suggests that the nonlinear function incorporated into the PID controller plays a crucial role in enhancing the overall accuracy of the system, particularly in maintaining a stable and precise output over time. In contrast, the conventional PID controller, despite delivering a rapid initial response, exhibits a higher IAE due to overshoot and the resulting oscillations before reaching steady state. This significant overshoot leads to larger deviations from the setpoint, thereby increasing the total absolute error. Meanwhile, the SMC offers solid performance, though it falls short of the accuracy achieved by the SN-PID and MN-PID controllers.

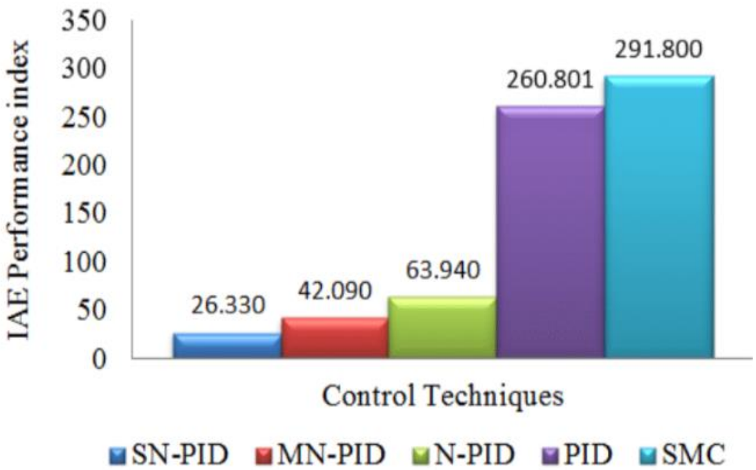

Figure 6. IAE Performance index for the system with different controllers

The findings indicate that the SN-PID and MN-PID controllers are developed with a strong emphasis on achieving both rapid response and high accuracy. Initially, the PID parameters are set with minimal emphasis on piston speed, allowing the system to operate effectively under various conditions. Once stable performance without overshoot is achieved, the response speed is enhanced by introducing a nonlinear gain, which improves transient performance. While increasing the nonlinear gain typically reduces system performance due to a lower gain margin, the SN-PID and MN-PID controllers maintain their effectiveness because the nonlinear gain dynamically adjusts based on the error and returns to its initial value once the desired input is achieved. The quantitative relationship between nonlinear gain for the damped frequency and peak time can be plotted in Figure 7. The results regarding the relationship between these three parameters confirm that the piston's velocity notably spikes at the beginning, as indicated by the short peak time (t_p). This spike leads to a brief overshoot in the system's response, driven by the rise in the damped frequency (ω_d). However, the impact of this overshoot is minimized by the reduction in the nonlinear amplification factor over time.

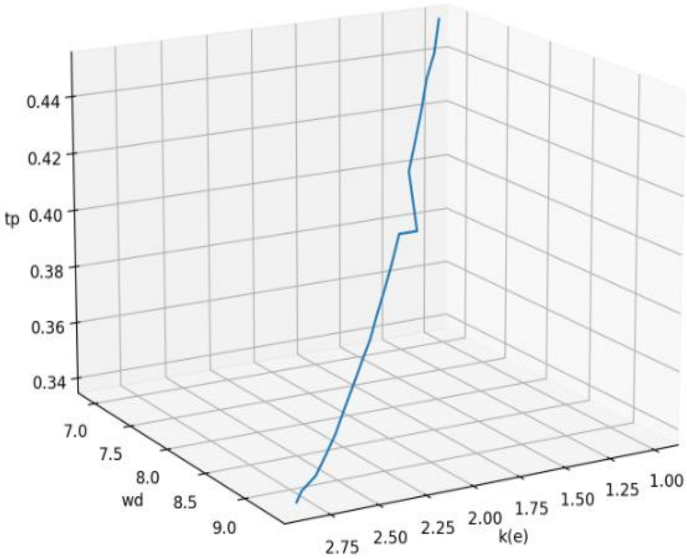

Figure 7. Relationship between nonlinear gain, $k(e)$, damping frequency (ω_d) and peak time (t_p)

3.2. Robustness performance

Robustness can be defined as the ability of a control system to remain insensitive to variations in plant parameters. This characteristic is crucial for ensuring consistent performance and reliability in real-world applications, where system parameters can change due to various factors such as environmental conditions, disturbances, and load variations. To thoroughly assess the system's robustness, a series of investigations were conducted, focusing primarily on the controller's ability to manage motion under varying load conditions. This aspect is critical because, in practical situations, the system may need to handle loads that differ significantly from the nominal design specifications.

In the first set of experiments, different masses were connected to the end of the stroke to simulate varying load conditions. The masses used in these experiments ranged up to 36.5 kg. By subjecting the system to these varying loads, the tests aimed to evaluate how well the controller could maintain stability and performance despite the changes in load. Additionally, experiments were conducted with different nominal loads to further understand the system's robustness. These tests involved altering the baseline load conditions and observing the controller's performance in maintaining the desired motion and stability. The ability to handle different nominal loads without significant degradation in performance is a key indicator of the controller's robustness. Overall, these investigations provide valuable insights into the robustness of the control system, highlighting its ability to adapt and perform reliably under varying operational conditions.

3.2.1. Performance analysis on the variation of load

This study investigates the results from a series of experiments conducted with varying loads. The system is tested using a step response with a displacement of 200 mm. The moving mass of the horizontal cylinder is attached to loads of $3.1\ kg$, $8.4\ kg$, $13.5\ kg$, $18.7\ kg$, $23.9\ kg$, $29.2\ kg$, and $36.5\ kg$. The controllers under investigation are benchmarked against each method, including conventional PID, Nonlinear PID, SN-PID, MD-PID, and SMC, using the same test rig. The performance details of the system under various controllers are summarized in Table 1.

Table 1. Performance results of control techniques under various load

Mass (kg)	Conventional PID			N-PID			MN-PID			SN-PID			SMC		
Load	$t_s(s)$	$\%OS$	e_{ss}	$t_s(s)$	$\%OS$	e_{ss}	$t_s(s)$	$\%OS$	e_{ss}	$t_s(s)$	$\%OS$	e_{ss}	$t_s(s)$	$\%OS$	e_{ss}
3.1	1.61	0.3	0.3	1.56	-	0.02	0.63	-	0.02	0.63	-	0.01	1.12	-	0.12
8.4	3.12	24	0.3	1.56	-	0.02	0.71	-	0.02	0.72	-	0.01	1.11	-	0.13
13.5				1.55	5.68	0.01	0.77	-	0.02	0.78	-	0.01	1.11	-	0.12
18.7				1.58	5.7	0.02	0.79	-	0.02	0.78	-	0.01	1.13	1.40	0.13
23.9		**unstable**		1.84	5.69	0.05	0.86	-	0.02	0.83	-	0.02	1.43	6.50	0.13
29.2				1.86	6.97	0.07	0.93	1.21	0.02	0.83	-	0.02	1.62	11.10	0.14
36.5				1.89	8.89	0.09	1.64	10.2	0.02	0.87	-	0.02	1.98	13.90	0.13

The results suggest that the SN-PID controller surpasses alternative techniques, as depicted in Figure 8, wherein the system employing this controller displays no overshoot even with a mass augmentation of 36.5 kg. Correspondingly, the MN-PID controller eradicates overshoot for payloads below 24 kg. Nevertheless, systems regulated by N-PID and SMC encounter unavoidable overshoot when the load surpasses 13.5 kg and 18.7 kg, respectively. On the contrary, the traditional PID controller exhibits the poorest performance, incapably sustaining stability beyond a mass of 8.4 kg. The SN-PID controller consistently exhibits superior efficacy in comparison to other methodologies. As illustrated in Figure 9, the settling time for the system utilizing the SN-PID controller remains minimal, remaining under 0.2 seconds. This emphasizes that the SN-PID approach significantly bolsters system robustness. The steady-state error stays within acceptable limits, showing only a slight increase when the mass reaches 36.5 kg. Conversely, the settling time of the MN-PID controller deteriorates once the mass exceeds 29 kg due to oscillations that impair system performance.

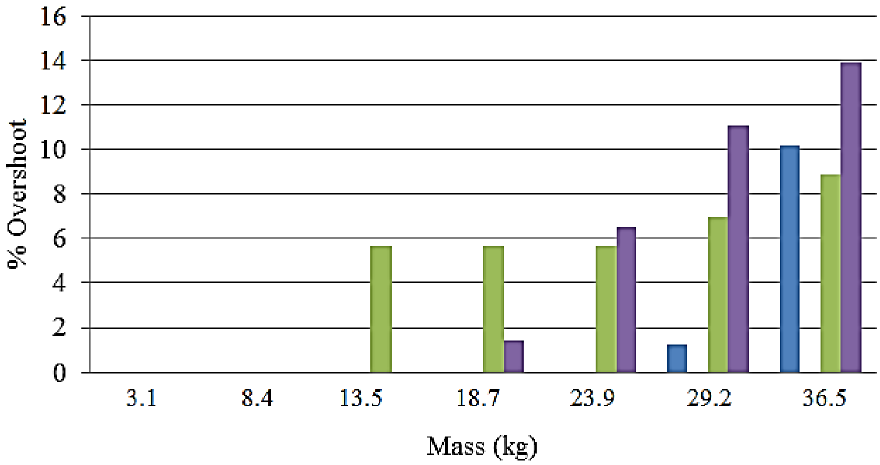

Figure 8. System overshoot vs different loads

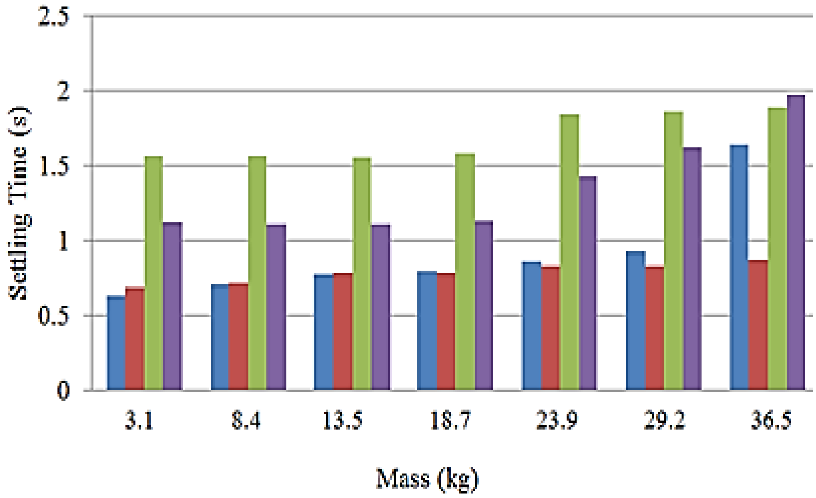

Figure 9. Settling time vs different loads

These findings potentially offer various practical implications for diverse engineering applications. By showing that MN-PID and SN-PID controllers offer lower overshoot rates and quicker settling times, this study underscores their role in improving system accuracy and stability. In practical applications, such as those in manufacturing, robotics, and others, incorporating these techniques can enhance performance, reduce errors, and improve product quality. This leads to greater operational efficiency and less downtime.

Additionally, their ability to rapidly stabilize systems under varying loads enhances the reliability and safety of critical operations, resulting in more robust and efficient engineering solutions.

4. CONCLUSION

In the performance comparison of various control methods, the SN-PID and MN-PID controllers demonstrate superior performance. Both controllers achieve the lowest integrated absolute error (IAE) values, effectively minimizing deviations from the desired setpoint over the testing period. The SN-PID controller, in particular, exhibits the best steady-state performance and remains robust under varying load conditions up to 36.5 kg, showing minimal overshoot and consistent settling times. The N-PID controller shows good performance with relatively low IAE and steady-state performance comparable to the SN-PID controller, although it has a slower transient response. The conventional PID controller, while providing a fast-initial response, suffers from significant overshoot and higher IAE, indicating lower robustness and less effective management of system dynamics. The SMC, although robust, does not match the precision of the SN-PID and MN-PID controllers, showing moderate effectiveness in minimizing error. Overall, the SN-PID controller is the most effective in maintaining system stability and performance across various conditions, followed closely by the MN-PID controller. This control strategy offers better handling of system dynamics and disturbances, resulting in improved accuracy and robustness.

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AUTHOR CONTRIBUTIONS STATEMENT

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Lokman Abdullah		✓	✓		✓		✓		✓	✓			✓	✓
Shamsul Anuar Shamsudin	✓			✓		✓	✓			✓	✓			
Khairun Najmi		✓	✓			✓	✓			✓	✓			
Mazree Ibrahim	✓			✓		✓	✓			✓	✓			

C : **C**onceptualization	I : **I**nvestigation	Vi : **Vi**sualization
M : **M**ethodology	R : **R**esources	Su : **Su**pervision
So : **So**ftware	D : **D**ata Curation	P : **P**roject administration
Va : **Va**lidation	O : Writing - **O**riginal Draft	Fu : **Fu**nding acquisition
Fo : **Fo**rmal analysis	E : Writing - Review & **E**diting	

CONFLICT OF INTEREST STATEMENT

The authors declare that there are no conflicts of interest, whether financial, personal, or professional, that could have influenced the research presented in this paper.

DATA AVAILABILITY

The data that support the findings of this study are available upon request to the corresponding author, Syed Najib Syed Salim.

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