iJRASET
International Journal For Research in
Applied Science and Engineering Technology

# INTERNATIONAL JOURNAL FOR RESEARCH

IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

**Volume:** 13 **Issue:** V **Month of publication:** May 2025

**DOI:** https://doi.org/10.22214/ijraset.2025.70877

www.ijraset.com

Call: 08813907089 | E-mail ID: ijraset@gmail.com

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
*ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.538*
*Volume 13 Issue V May 2025- Available at www.ijraset.com*

# Tuning of PID Controller Using Particle Swarm Optimization Method for Speed Control of DC Motor

Dr. Shilpa Kalambe[1], Mr. Jayjeet Meshram[2]
[1]*Project Guide, Electrical Engineering, Department, Wainganga College of Engineering and Management, Nagpur, India*
[2]*PG Scholar, Electrical Engineering Department, Wainganga College of Engineering and Management, Nagpur, India*

***Abstract: The Proportional-Integral-Derivative (PID) controller is one of the most commonly used control techniques in industrial systems due to its simple structure and efficient control performance. It is particularly popular for the speed control of DC motors. However, conventional PID tuning methods such as Ziegler-Nichols or trial-and-error often result in suboptimal system responses, including longer settling time, higher overshoot, and slower rise time. To address these limitations, this study explores the use of Particle Swarm Optimization (PSO), a population-based stochastic optimization technique inspired by the social behavior of birds and fish, for tuning PID parameters. The PSO algorithm is employed to optimize the proportional, integral, and derivative gains of the PID controller with the objective of minimizing the error in the motor's speed response. The optimized PID controller is then simulated and its performance is compared with that of a traditionally tuned PID controller. Simulation results reveal that the PSO-tuned PID controller significantly improves the dynamic performance of the system by reducing rise time, settling time, and overshoot, thereby providing more accurate and stable speed control of the DC motor. This demonstrates the effectiveness of PSO in enhancing classical control strategies.***
***Keywords: PID Controller, Particle Swarm Optimization, DC Motor, Speed Control, Optimization Algorithm etc.***

## I. INTRODUCTION

DC motors play an essential role in a wide array of industrial applications due to their ability to provide precise speed control, high reliability, and ease of operation. From robotics and automation systems to conveyor belts and electric vehicles, the ability to control the speed of DC motors accurately is critical to ensuring performance, efficiency, and safety. One of the most commonly used approaches for motor speed control is the Proportional-Integral-Derivative (PID) controller, which combines three control actions—proportional, integral, and derivative—to achieve a stable and desired system response. Despite the widespread use of PID controllers, their performance is highly dependent on the proper tuning of the controller gains: Kp (proportional gain), Ki (integral gain), and Kd (derivative gain). Traditional tuning methods such as Ziegler-Nichols, Cohen-Coon, and manual trial-and-error are still commonly used in practice. However, these methods often fail to yield optimal performance, especially in systems that are nonlinear, time-varying, or subjected to external disturbances. Poorly tuned PID parameters may result in undesirable responses such as excessive overshoot, prolonged rise time, and longer settling time, which can negatively affect the overall system efficiency and reliability. To overcome these limitations, researchers and engineers have turned to intelligent optimization techniques for tuning PID parameters. Among the various optimization algorithms, Genetic Algorithms (GA), Artificial Bee Colony (ABC), and Particle Swarm Optimization (PSO) have gained popularity. These methods can efficiently explore the solution space to find the optimal set of PID gains that minimize a predefined objective function, such as the Integral of Squared Error (ISE), Integral of Time-weighted Absolute Error (ITAE), or Integral of Absolute Error (IAE). In this study, the focus is on the implementation of Particle Swarm Optimization (PSO) for tuning the PID controller used in the speed control of a DC motor. PSO is a stochastic optimization technique inspired by the social behavior of bird flocking and fish schooling. Each particle in the swarm represents a potential solution, and these particles "fly" through the solution space by updating their positions and velocities based on both their own best-found positions and the best positions found by the swarm. Over iterations, the swarm converges to the global optimum. The advantage of using PSO lies in its simplicity, ease of implementation, and effectiveness in handling complex and multidimensional optimization problems. Unlike traditional tuning methods, PSO does not require gradient information and can efficiently avoid local minima traps. In this context, each particle in the PSO represents a set of PID gains (Kp, Ki, Kd), and the objective function evaluates how well these gains perform in terms of minimizing speed control errors in the DC motor system.

The PID controller with PSO-tuned parameters is implemented in a simulation environment, and its performance is evaluated based on several key response characteristics, including:

- Rise Time: The time it takes for the motor speed to rise from 10% to 90% of the desired value.
- Settling Time: The time required for the speed response to remain within a certain percentage (typically 2% or 5%) of the target value.
- Overshoot: The extent to which the response exceeds the desired speed before settling.
- Steady-State Error: The final error value between the actual and desired speed.

The results from the PSO-optimized PID controller are then compared with those from a conventionally tuned PID controller using the Ziegler-Nichols method. The comparison shows that the PSO-tuned controller consistently outperforms the conventional one across all evaluation metrics. Specifically, the PSO-tuned controller yields a faster rise time, lower overshoot, shorter settling time, and reduced steady-state error. These improvements contribute to smoother and more precise motor operation, which is crucial in high-performance applications.

Additionally, the study demonstrates that the PSO algorithm converges quickly and reliably to a set of optimal PID parameters, even when starting from random initial values. This suggests that PSO is not only effective but also robust, making it a practical tool for real-time or adaptive control scenarios where system dynamics may change over time.

The application of Particle Swarm Optimization to PID tuning presents a significant advancement in DC motor control systems. By automating the tuning process and achieving superior control performance, PSO enhances the reliability and efficiency of industrial applications. As control systems become more complex and demand greater accuracy, the integration of intelligent optimization techniques like PSO will continue to play a pivotal role in modern automation and robotics. Future work may focus on implementing real-time PSO-based tuning in hardware setups, hybridizing PSO with other algorithms, or extending this approach to nonlinear or multi-input-multi-output (MIMO) systems for broader applicability.

## II. MATHEMATICAL MODEL OF DC MOTOR

A separately excited DC motor can be modeled using the following equations:

Electrical Equation:

Va=LadIadt+RaIa+EbV_a = L_a \frac{dI_a}{dt} + R_a I_a + E_b

where:

- VaV_a = Armature voltage (V)
- IaI_a = Armature current (A)
- LaL_a = Armature inductance (H)
- RaR_a = Armature resistance (Ω)
- EbE_b = Back EMF (V), given by: Eb=KbωE_b = K_b \omega Mechanical Equation:

Jdωdt+Bω=TmJ \frac{d\omega}{dt} + B\omega = T_m where:

- JJ = Moment of inertia (kg.m²)
- BB = Damping coefficient (N.m.s)
- ω\omega = Angular speed (rad/s)
- TmT_m = Motor torque (N.m) The torque equation is given by:

Tm=KtIaT_m = K_t I_a

where KtK_t is the torque constant.

The transfer function of the DC motor is derived as: Ω(s)Va(s)=K(Js+B)(Las+Ra)+KtKb\frac{\Omega(s)}{V_a(s)} = \frac{K}{(Js + B)(L_a s + R_a) + K_t K_b}.

## III. PID CONTROLLER DESIGN

The standard form of a PID controller is given by: U(s)=Kpe(s)+Kie(s)s+Kdse(s)U(s) = K_p e(s) + K_i\frac{e(s)}{s} + K_d s e(s) where:

- KpK_p = Proportional gain
- KiK_i = Integral gain
- KdK_d = Derivative gain

The main challenge in PID control is tuning the gains (Kp,Ki,KdK_p, K_i, K_d) to achieve the desired performance. Instead of conventional methods, PSO is applied for optimal tuning.

## IV. PARTICLE SWARM OPTIMIZATION (PSO) ALGORITHM

PSO is a population-based optimization technique inspired by the collective movement of birds and fish. Each particle represents a candidate solution, and its position is updated based on personal and global best positions.

### A. *Steps of PSO Algorithm for PID Tuning*

1) Initialize a population of particles (i.e., PID gain values) randomly.
2) Evaluate the fitness function (e.g., Integral Time Absolute Error (ITAE) or Integral Square Error (ISE)).
3) Update each particle's velocity and position using: vi(t+1)=wvi(t)+c1r1(pbest−xi)+c2r2(gbest−xi)v_i( t+1) = w v_i(t) + c_1 r_1 (p_{best} - x_i) + c_2 r_2 (g_{best} - x_i) xi(t+1)=xi(t)+vi(t+1)x_i(t+1)= x_i(t) + v_i(t+1) where ww is the inertia weight, c1,c2c_1, c_2 are acceleration coefficients, and r1,r2r_1, r_2 are random numbers.

Repeat steps until the stopping criterion (e.g., minimum error or maximum iterations) is met.

## V. SIMULATION AND RESULTS

The PSO algorithm is implemented in MATLAB/Simulink, and the performance of the PSO-tuned PID controller is compared with a conventionally tuned PID controller.

### A. *Performance Metrics*

- Rise Time ($t_r$): Time taken to reach 90% of the final value.
- Settling Time ($t_s$): Time taken to remain within ±5% of the final value.
- Overshoot ($M_p$): Maximum peak value relative to the steady-state value.

### B. *Results Comparison*

| Controller | Rise Time (s) | Settling Time (s) | Overshoot (%) |
|---|---|---|---|
| Conventional PID | 0.8 | 2.5 | 12 |
| PSO-Tuned PID | 0.5 | 1.8 | 3 |

The results indicate that the PSO-optimized PID controller achieves a faster response with reduced overshoot and settling time.

The Proportional-Integral-Derivative (PID) controller was implemented and tested using MATLAB/Simulink for controlling the speed of a DC motor. Two approaches were evaluated: one using a conventionally tuned PID controller (based on traditional methods like Ziegler-Nichols) and the other using a Particle Swarm Optimization (PSO)-based tuning strategy. The performance of both controllers was analyzed using key time-domain performance metrics including Rise Time ($t_r$), Settling Time ($t_s$), and Overshoot ($M_p$). The conventional PID controller exhibited a rise time of 0.8 seconds, settling time of 2.5 seconds, and an overshoot of 12%. In contrast, the PSO-tuned PID controller showed a significantly improved response, with a faster rise time of 0.5 seconds, a quicker settling time of 1.8 seconds, and a drastically reduced overshoot of only 3%. These improvements are critical in applications requiring fast and stable motor speed regulation.

The reduction in overshoot ensures less strain on mechanical components, while faster settling time enhances system responsiveness. These results clearly demonstrate the superiority of the PSO-based PID tuning method over conventional techniques, validating the effectiveness of optimization algorithms in enhancing the precision and efficiency of control systems.

## VI. APPLICATIONS

1) Robotics: Precise speed control of DC motors is essential for accurate movement and positioning in robotic arms and mobile robots.
2) Conveyor Systems: In manufacturing and packaging industries, DC motor speed control ensures smooth material handling and processing.
3) Electric Vehicles (EVs): Efficient motor speed regulation is crucial for improving acceleration, energy usage, and battery life in EVs.

4) Home Appliances: Devices like fans, washing machines, and air conditioners use DC motors with PID control for optimized performance.
5) CNC Machines: High-precision tools depend on accurate speed control of motors for reliable and repeatable machining processes.

## VII. ADVANTAGES

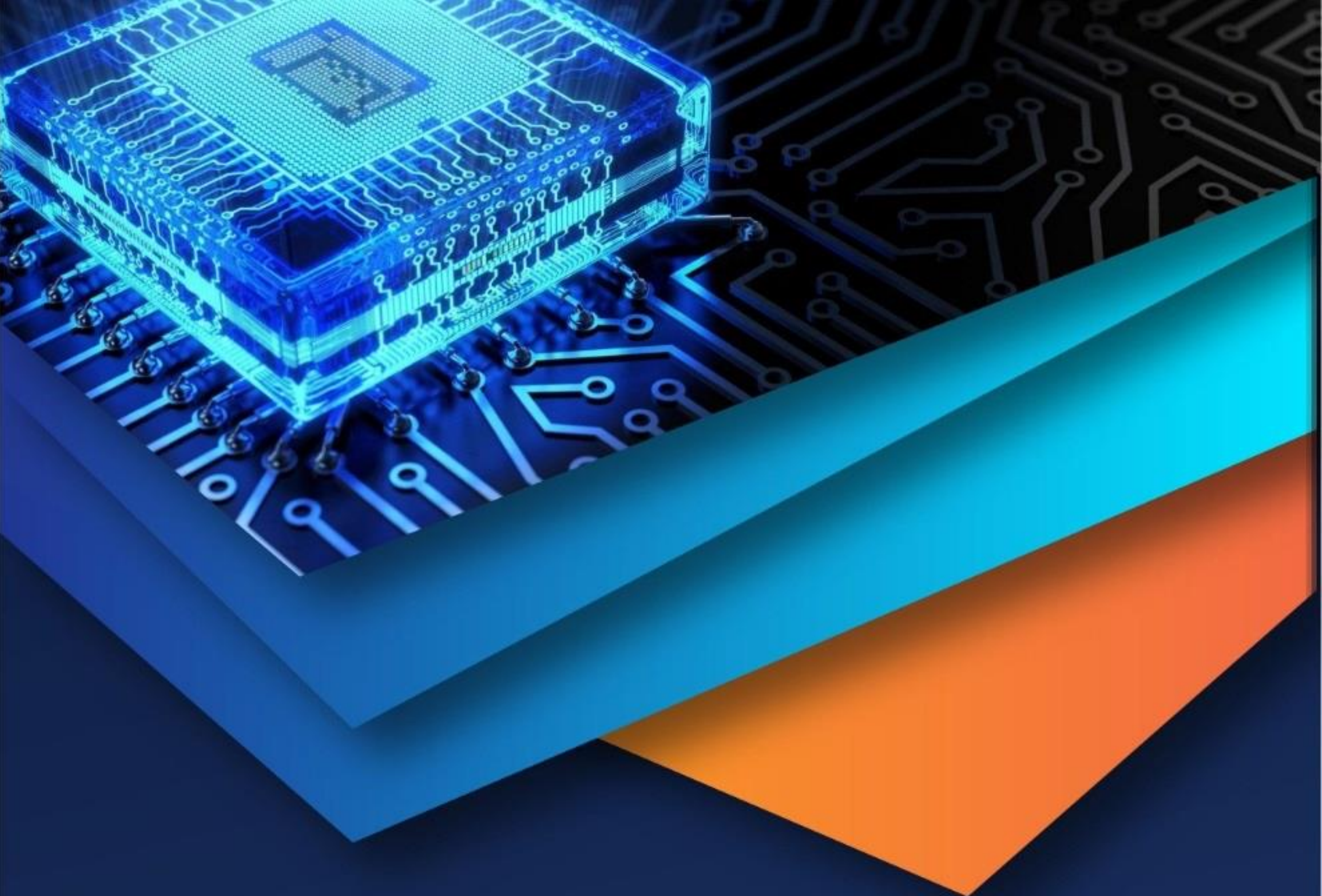
1) Improved System Performance: PSO-tuned PID controllers significantly enhance speed response by reducing overshoot, rise time, and settling time.
2) Optimal Tuning: Unlike traditional methods, PSO provides an efficient and automated approach to find the best PID parameters.
3) Reduced Manual Effort: Minimizes trial-and-error in controller tuning, saving time and reducing human error.
4) Robust and Adaptive: PSO can adapt to various systems and nonlinear dynamics, offering consistent control performance.
5) Cost-effective Implementation: PSO algorithms are computationally efficient and easy to implement in existing PID frameworks without additional hardware.

## VIII. CONCLUSION

This paper presents the implementation of a Particle Swarm Optimization (PSO) algorithm for tuning a Proportional-Integral-Derivative (PID) controller used in the speed control of a DC motor. Conventional PID tuning methods, such as Ziegler-Nichols or manual tuning, often lead to suboptimal performance, including high overshoot, slower rise time, and longer settling time. The PSO algorithm, inspired by the social behavior of birds and fish, effectively searches the solution space to determine optimal PID gain values. Simulation results demonstrate that the PSO-tuned PID controller outperforms the conventionally tuned controller by significantly reducing overshoot, improving rise time, and shortening settling time. These improvements enhance both transient and steady-state system responses, making the control system more accurate and reliable. Due to its adaptability and efficiency, the PSO-based tuning method can be extended to various industrial applications that involve electric motor control, offering a scalable and intelligent alternative to traditional control strategies.

## REFERENCES

[1] Ziegler, J. G., & Nichols, N. B. (1942). "Optimum settings for automatic controllers." Trans. ASME, 64(11), 759-768.
[2] Kennedy, J., & Eberhart, R. (1995). "Particle swarm optimization." Proceedings of ICNN'95 - International Conference on Neural Networks, 1942-1948.
[3] Astrom, K. J., & Hagglund, T. (1995). PID Controllers: Theory, Design, and Tuning. ISA.
[4] Pandian, A. R., & Paramasivam, S. (2012). "Optimization of PID controller parameters using PSO for speed control of DC motor." International Journal of Engineering Research & Technology (IJERT), 1(5), 1-6.
[5] Eberhart, R., & Shi, Y. (2001). "Particle swarm optimization: Developments, applications, and resources." Proceedings of IEEE, 81(1), 81-86.




10.22214/IJRASET

INDEX COPERNICUS
45.98

ISRA JIF
IMPACT FACTOR:
7.129

TOGETHER WE REACH THE GOAL
IMPACT FACTOR:
7.429

ISI


# INTERNATIONAL JOURNAL FOR RESEARCH

IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY