



## Designing an Optimal Pid Controller For DC Motor Speed Regulation through Smell Agent Optimization Algorithm

Abel E. Airoboman, I. U. Yusuf, T. Tajudeen  
Department of Electrical/Electronic Engineering,  
Nigerian Defence Academy, Kaduna

### ABSTRACT

This paper presents an optimal PID controller for speed control of DC motor using Smell Agent Optimization (SAO) Algorithm. DC Motor is an energy converter which transforms electrical energy into mechanical energy used in several industrial applications. A SAO based PID is proposed for optimal tuning of the parameters of the controller to improve speed control of the motor. The SAO uses the phenomenon of smell perception and the intuitive trailing behavior of an agent to identify the source of smell. The integral of time multiplied absolute error (ITAE) is taken as the objective function for obtaining the parameters of the PID controller. It has been observed SAO-PID controller outperforms the GA based PID controller with less settling time, rise time and overshoot.

### ARTICLE INFO

#### Article History

Received: November, 2025

Received in revised form: December, 2025

Accepted: February, 2026

Published online: March, 2026

### KEYWORDS

DC Motor, PID Controller, Rising Time, Settling Time, Smell Agent Optimization Algorithm

### INTRODUCTION

DC Motor is an energy converter which transforms an electrical energy into mechanical energy (Kushwah & Patra, 2024). Speed control of DC motor can be done by either keeping the armature winding current constant or the field winding current constant to achieve an excellent speed performance over a wide range of values (Sabir & Khan, 2024). DC motors are used several applications as in robotics, electric cranes, electric vehicles, disk drivers (Agnihotri *et al.*, 2021; Kumar & Dohare, 2024). Features of DC motor include high starting torque, portability, and conformity with different types of tuning methods (Abdulameer *et al.*, 2023). Among the merits of DC motors include: easy to control, low maintenance, cheap and also rugged (Sabir & Khan, 2024). Various types of controllers include: lead, lag, LQR (linear quadratic regulator), PID (Proportional Integral Derivative) and slide mode control, could be integrated in control applications (Sabir & Khan, 2024).

In industries, over 95% of the controllers used are PID controllers, this is due to its high efficiency and ease of implementation. It has been used for several decades in industrial process applications. It has a disadvantage of; unsuitable

speed overshoot and slow response to sudden change in load torque and sensitivity to controller gains. Designing a PID controller mechanism requires tuning of three parameters; proportional gain  $k_p$ , integral gain  $k_i$  and derivative gain  $k_d$ .

For optimal operation of a controller, the main aim of the controller is to minimize steady state error, rise time, overshoot and settling time. The performance of the controller depends on the accuracy of system design parameters (Mirzaei & Moattar, 2025). Techniques used for tuning a PID controller can be classified into two categories namely: the classical approaches and the metaheuristics techniques (Bansal *et al.*, 2022).

In the classical approaches, Assumptions are made on the plant and the desired output to obtain the design parameters analytically or graphically (Bansal *et al.*, 2022). The advantages of these techniques are; they are computationally fast, simple to implement and are good at first iteration. A disadvantage of these techniques is that, skill and experience are required in tuning a PID controller using the classical approach. Examples of the classical include; Ziegler method, Cohen coon method and Nichols's method. In recent years, metaheuristics optimization techniques had been applied in every

Corresponding author: I. U. Yusuf

[yusufman281@gmail.com](mailto:yusufman281@gmail.com)

Department of Electrical/Electronic Engineering, Nigerian Defence Academy, Kaduna.

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discipline (Sabir & Khan, 2014). A wide range of metaheuristic algorithms have been developed over the last three decades, and many metaheuristics are increasingly becoming popular (Yang, 2021). These metaheuristic techniques have been applied on control systems, and the results obtained show significant improvement over classical techniques (Ekinci et al., 2025).

Abdulameer et al., (2023) designed a PID controller for DC speed motor using the Ziegler-Nichols and Chien-Hrones-Reswick method. Results show that the Ziegler-Nichols has a faster system response with acceptable overshoot, while the Chien-Hrones-Reswick method has lower overshoot with acceptable transient response. Meena & Chahar, (2017) design a speed control DC motor using Genetic Algorithm. The GA PID was compared to Ziegler-Nichols (ZN) methods, and the results show that the proposed GA gives less overshoot and less settling time, thus, it performs better than ZN. Taki El-Deen et al., (2015) designed an optimal PID tuning for DC motor based on Genetic Algorithm (GA) and Active Set Optimization Algorithm (ASOA). Simulation results show that the system performance was enhanced for GA-PID as compared to the ASOA-PID.

Solihin et al. (2021) design a PID controller using Particle Swarm Optimization (PSO) algorithm. Results obtained show less overshoot compared to the ZN method. Agnihotri et al., (2021) designed a PID controller tuned by PSO and Improved Grey Wolf Optimizer (IGWO) for a DC motor. Results obtained show that the PSO and IGWO improve the performance characteristics of the DC motor, however, the IGWO has a better performance and owns good robustness towards the PSO. Obeng & Karam, (2023) proposed a PSO to the PID speed control of a permanent magnet DC motor. The PSO-PID was successful in reducing the overshoot and settling time of the DC Motor speed response. Ekinci et al., (2025) designed a PID tuned controller for the regulation of the speed of DC motor using the Harris Hawk Optimization (HHO) algorithm. Results obtained show that the HHO PID controller outperforms the atomic search

optimization PID and the sine cosine algorithm PID

Sabir & Khan, (2024) proposed a PID controller for speed control in a DC motor using a hybrid of Nelder-Mead (NM) method and PSO, GA and simulated annealing (SA). Results obtained for metaheuristic techniques show substantial improvement on the rise time, settling time and peak overshoot as compared to classical methods. The NM-SA method is more robust as compared to NMGA and NM-PSO, GA, PSO and SA technique. Ibrahim & Mahmoud, (2014) proposed an improved ant colony optimization (ACO) for optimal tuning of PID parameters. The results obtained show that the ACO has self-adaptation and positive feedback process to escape the trap of local minimum and achieve the best solution. The aim of this paper is to design a PID controller for speed control in DC motor using smell agent optimization algorithm. The results are compared to GA-PID controller, which is one of the most robust PID Controller. The system design requirement for the DC Motor is to have a settling time of less than 2 secs, the overshoot should be less than 5% and steady state error of not more than 1%.

### Mathematical Model of DC Motor

A separately excited DC motor is shown in Fig. 1.

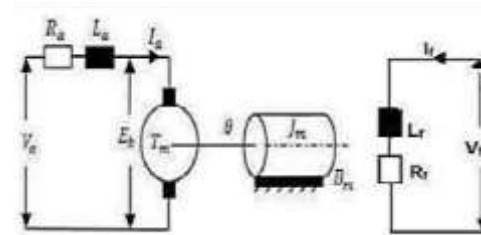


Fig. 1: Separately Excited DC Motor (Ibrahim & Mahmoud, 2022)

The equations governing the operation of a separately excited motor can be determined as:

$$V_a = I_a R_a + L_a \frac{di_a}{dt} + E_b \quad (1)$$



$V_a$  is the motor voltage,  $I_a$  is the armature current,  $R_a$  is the armature resistance,  $L_a$  is the armature inductance,  $E_b$  is back EMF

$$E_b = k_b \omega I_f \quad (2)$$

$K_b$  is electromotive force constant, where  $\omega$  the speed of the motor,  $I_f$  is field current

$$T_d = k_t I_f I_a \quad (3)$$

$T_d$  is motor developed torque,  $k_t$  is torque constant

$$T_d = J_m \frac{d\omega}{dt} + B\omega + T_L \quad (4)$$

$J_m$  is the moment of inertia,  $B$  is damping ratio and  $T_L$  is load torque.

The transfer function of a DC motor considering the field current constant can be described as (Obeng & Karam,

$$G_m = \frac{\omega(s)}{V_a(s)} = \frac{k_t}{(J_m s + B)(R_a + L_a s) + k_t k_b} \quad (5)$$

The values of this parameters are adopted from the DC motor Pittman Model 9234S004 which are provided in Table 1 (Ibrahim & Mahmoud, 2014).

Table 1. DC Motor

Paramete	Value
$k_t$	$18 \times 10^{-2} N / A$
$k_b$	$18 \times 10^{-2} v / ra$
$R_a$	$0.8 \Omega$
$L_a$	$0.6 m$
$J_m$	$4.2 \times 10^{-6} k m^2 / ra$
$B$	$2.6 \times 10^{-6} Nm$

## PID CONTROLLER

The PID controller is widely used in industries to solve various control problems. The main role of the PID controller is to make the plant less sensitive to changes in the surrounding (Taki El-Deen et al., 2015). The controller tries to minimize the error by adjusting the process control input (Kushwah & Patra, 2014). The PID controller calculation involves three constant parameters:  $k_p$ ,  $k_i$  and  $k_d$ . Fig. 2 shows a block diagram of PID controller.

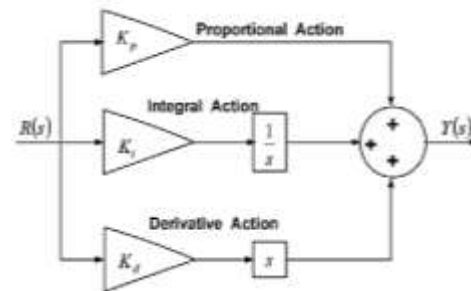


Fig. 2: Block diagram of PID Controller (Meena & Chahar, 2017)

The transfer function of PID controller is expressed as:

$$G_{PID} = k_p + \frac{k_i}{s} + k_d s \quad (6)$$

In the design of PID controller using meta-heuristic techniques for PID tuning. The meta-heuristic techniques require cost functions for error minimization (Bansal et al., 2012). The four commonly used cost functions include: Integral Absolute Error (IAE). The integral square error (ISE), The integral time absolute error (ITAE), Integral time square error (ITSE). In this paper, a SAO-PID controller was employed for speed control of a DC Motor. The ITAE was taken as objective function for tuning the PID controller as shown in Equation (7).

$$\left| 1 - \frac{G_m(s)G_{PID}(s)}{1 - G_m(s)G_{PID}(s)} \right| \quad (7)$$

Subject to the following constraint:

$$(0.0001 \leq k_p \leq 100)$$

$$(0.0001 \leq k_i \leq 100)$$

$$(0.0001 \leq k_d \leq 50)$$

## Smell Agent Optimization

The Smell Agent Optimization (SAO) was developed in 2018 by Salawudeen et al. (2018). It uses the phenomenon of smell perception and the intuitive trailing behavior of an agent to identify the source of smell. The algorithm was tested on standard bench mark test functions and compared to PSO, GA and Ant Bee Colony algorithm (ABC). The results observed shows the

SAO is highly efficient and can also compete with meta-heuristic algorithms reported in the literature (Salawudeen et al., 2018). Table 2 shows the pseudo-code for SAO algorithm (Salawudeen et al., 2020). The SAO operates in three distinct modes (Salawudeen et al., 2020):

- 1) Sniffing Mode: The ability of an agent to perceive smell from a substance in an environment. The agent evaluates the concentration of the smell and decides to follow the smell molecules direction or not.
- 2) Trailing Mode: In the process of exploring the search space, the concentration of smell molecules may become higher than the current position of the agent, the agent moves towards that position.
- 3) Random Mode: The concentration of smell varies over time from one point to another, thereby confusing the agent, and the agent may lose the smell in
- 4) trailing process. The agent may be trapped at local optimum, the agent then moves randomly hoping to find the smell molecule again.

Table 2. SAO Algorithm Pseudo-code

Let N: Number of Smell molecules;  
 D: Search space where the smell molecules evaporate

- a. Initialize SAO parameters ( $k_{olf}, T, m$ )
- b. Randomly initialize smell molecules and its velocity
- c. For each molecule from 1 to N
  - i. Update molecules velocity and position
  - ii. Evaluate fitness
  - iii. Determine agent position and worst molecules position
  - iv. Evaluate the random mode and its fitness
  - v. If ii is better than iv move to vi else move to d
  - vi. Evaluate the random mode and its fitness
- d. Repeat step c until maximum iteration is reach

- e. Sort all molecules and determine the smell source.

## RESULTS AND DISCUSSION

Referring to Equation (5), substituting the design parameters in Table 1, the transfer function of the DC motor was obtained as shown in Equation (8).

$$G_m = \frac{0.0182}{2.64 \times 10^{-10} s^2 + 3.486 \times 10^{-6} s + 0.000334} \quad (8)$$

From Equation (8), it can be seen that the DC motor is a second order system. Figure 3 shows the open loop response of the DC Motor to a unit step input. The closed loop response of the DC Motor to a unit step input is presented in Fig.4. It can be observed from Fig. 1 and Fig. 4, the DC Motor exhibit damped oscillation before attaining a steady state.

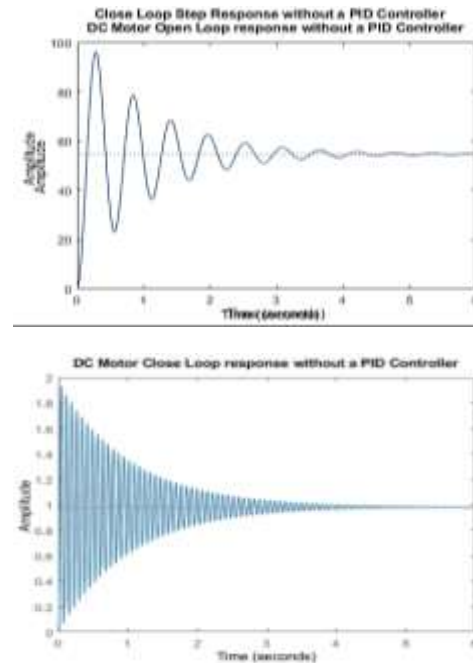


Fig 3:& Fig 4 Open and Closed loop step response of a DC motor

### SAO PID CONTROLLER

Table 3 is the summary of the DC Motor characteristics for both the open and closed loop

Table 3. DC Motor Step Response

Parameter	Open Loop	Closed Loop
Overshoot (%)	76.18	96.43
Rise Time, (Tr)	0.099s	0.013s
Settling Time (Ts)	3.973s	4.019s

### SAO PID CONTROLLER

The SAO- PID controller was designed for the optimal tuning of the controller parameters to reduce the error between the system output and the desired output. SAO-PID algorithm was implemented in MATLAB R2020A using Equation (7) as objective function to minimize the error and determine the PID gain parameters. The parameters for the SAO-PID algorithm are presented in Table 4. A total number of 50 iterations was considered, it was observed that the error between the system output and the desired output kept decreasing as the number of iterations increases as shown in Fig. 4, the optimal values of  $k_p$ ,  $k_i$  and  $k_d$  are obtained at the 50<sup>th</sup> iteration

Table 4. Parameters of SAO-PID

Parameters	Value
Population	50
Number of Iteration	50

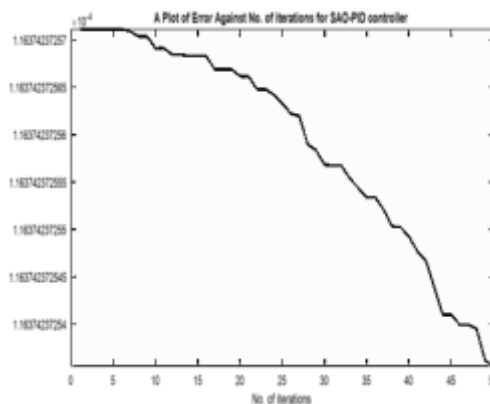


Fig. 5: Plot of Error against the Number of Iterations in SAO-PID Controller

Fig. 6 shows the step response of the DC Motor using the SAO-PID controller. It can be observed that the system overshoot is 0, rising time is  $7.214 \times 10^{-6}$  secs and the settling time  $1.254 \times 10^{-5}$  secs. The parameters for the optimal tuning of the SAO-PID algorithm are  $k_p=93.78$ ,  $k_i=45.39$  and  $k_d=44.28$

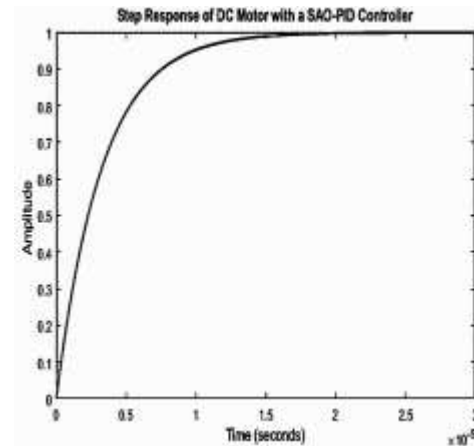


Fig. 6: Step Response of DC Motor Using SAO-PID Controller

### GA PID CONTROLLER

The GA-PID Controller was implemented in MATLAB R2022b toolbox using Equation (6) as objective function to minimize the error and determine the PID gain parameters. The parameters for the GA-PID algorithm are presented in Table 5.

Table 5. Parameters of GA-PID

Parameter	Value
Population	50
Number of iterations	50

Fig. 7 shows the step response of the DC Motor using the GA-PID controller. It can be observed that the system overshoot is 0.6458, rising time is  $2.311 \times 10^{-4}$  secs and the settling time is  $3.898 \times 10^{-4}$  secs. The parameters for the optimal tuning of the GA-PID controller are  $k_p=99.997$ ,  $k_i=99.999$  and  $k_d=1.351$

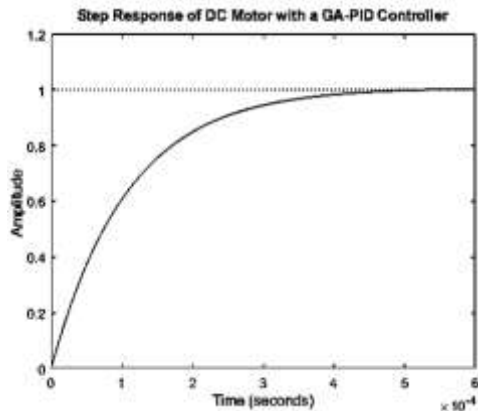


Fig. 7: Step response of the DC Motor using the GA-PID controller

### COMPARISON BETWEEN SAO-PID AND GA-PID

Fig. 8 shows the comparison between the step response of the DC Motor using the SAO-PID controller and the GAPID controller. It can be observed that both the SAO-PID and GA-PID satisfy the system design requirement of 2% overshoot and less than 1% settling time. The GA-PID controller converges faster than the SAO-PID controller, however the SAO-Controller is more robust than the GAPID controller. Table 6 shows the system characteristics for both the SAO-PID and the GA-PID.

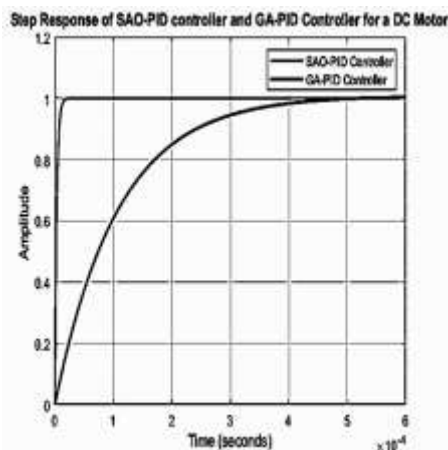


Fig. 8: Comparison between the step response of the DC Motor using the SAO-PID controller and the GA-PID controller

Table 6 Comparison between SAO-PID & GA-PID

	$k_p$	$k_i$	$k_d$	$e$
SAO-PID	93.78	45.39	44.28	$1.164 \times 10^{-5}$
GA-PID	99.9 GA-	99.999	1.351	$96.94 \times 10^{-5}$

### CONCLUSION

In this study, an optimal Smell Agent Optimization based PID Controller was developed. The ITAE is taken as the fitness function to study the rising time, settling time and overshoot of a DC Motor. The SAO-PID controller is applied to a DC Motor as a test benchmark for speed control. Results show that the SAO-PID has significantly enhanced the system performance and the system design goals are met. Further work could be carried out to study the performance of SAO on the optimal tuning of LQR controller.

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Corresponding author: I. U. Yusuf

[yusufman281@gmail.com](mailto:yusufman281@gmail.com)

Department of Electrical/Electronic Engineering, Nigerian Defence Academy, Kaduna.

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Corresponding author: I. U. Yusuf

[yusufman281@gmail.com](mailto:yusufman281@gmail.com)

Department of Electrical/Electronic Engineering, Nigerian Defence Academy, Kaduna.

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