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Modifying the DC Servo Motor Observed by Particle Swarm Optimization Techniques

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Abstract

The PID controller's optimized tuning improves the control system's functionality. This work presented the tuning of the PID/FOPID controller by the conventional Ziegler-Nichols (ZN) method and the Particle Swarm Optimization (PSO) algorithm. The PID controller is the most popular in the industry because it is simple to implement, has good computing ability, and provides a robust system. These methods are implemented on the DC servomotor system to optimize the transient responses like rise time (t_r), settling time (t_s), and peak overshoot (M_p) to get a better result. The PID controller tuned by the conventional ZN method gives a longer settling time, a longer rise time, and a higher peak overshoot. The PSO algorithm is utilized to overcome the significant overshoot and considerable settling time obtained in the conventional Ziegler-Nichols method. Analyzing and comparing the MATLAB simulation results, it is observed that PSO algorithms provide a better-optimized response over the ZN method with FOPID controller in respect of less rise time (t_r =0.0392 sec.), less settling time (t_s=0.0605 sec.) and peak overshoot (M_p=1.92%). The results obtained by the proposed controller provide better reliability and better response.

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INTRODUCTION

Servomotors are crucial components in many systems, transforming electrical signals into mechanical motion and driving the final control elements. For a servomotor to be efficient, it needs to accelerate quickly, maintain low inertia, and exhibit a linear relationship between torque and speed. Additionally, it should run smoothly without overshooting or fluctuating and be capable of handling high-frequency operations. Servomotors are broadly categorized into AC and DC types, with DC servomotors further divided into field-controlled and armature-controlled types. Armature-controlled DC servomotors are often preferred due to their quick response to current changes, making them ideal for tasks that require precise control of position and speed [1]. These motors are reliable and effective, essential for various household and industrial applications. However, controlling the speed of DC motors to perform specific tasks remains a common challenge. In today's world, optimization is paramount, aiming to achieve the highest efficiency and best performance. Researchers and industries continually explore and implement various optimization algorithms for optimal results. Optimizing a DC servomotor involves using traditional or

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newer artificial methods to find the best values for specific functions within given constraints. Traditional optimization methods, such as the ZN approach and its variations, enhance controller performance in closed-loop systems [2]. Standard controllers include proportional-integral (PI), proportional-integral-derivative (PID), and fuzzy logic controllers [3]. Modern algorithms, like genetic algorithms (GA) and PSO, are also employed to optimize control system responses. PID controllers are particularly popular in industrial settings, accounting for approximately 95% of closed-loop operations.

In summary, using advanced algorithms like PSO to optimize the performance of DC servomotors can significantly enhance their efficiency and reliability, making them even more valuable in various applications. This study focuses on the armature-controlled DC motor, which maintains torque by adjusting the armature current while the field current remains constant. This setup allows for optimized performance due to the closed-loop system. Our research aims to improve the transient response of the DC servomotor using the ZN method and PSO algorithm for tuning.

Permanent magnet DC motors serve as the most common prime movers in the industry. These motors act as torque converters, transforming electrical energy into mechanical energy. The torque the motor's shaft produces is directly proportional to the armature's current and the field's flux. This characteristic makes DC motors particularly valuable in industrial applications that require high torque, especially when handling heavy loads. A PID controller is often used to effectively control the speed of DC servomotors. The PID controller integrates three types of control mechanisms: proportional (P), integral (I), and derivative (D). These mechanisms generate a control signal that precisely adjusts the motor's speed. The P-controller addresses the current error, the I-controller accumulates past errors to eliminate steady-state error, and the D-controller predicts future errors to reduce overshoot [4]. PID controllers have diverse applications, including heat treatment of metals, drying, evaporation of solvents from painted surfaces, and curing rubber. Various tuning algorithms, such as PSO and GA, enhance PID controllers' performance [5]. PSO is frequently used to tune PID controllers in DC motors. Kennedy and Eberhart's introduction of the PSO algorithm drew inspiration from the coordinated actions of natural phenomena like fish and birds [6]. The particles in PSO, which stand in for possible solutions, learn from their surroundings and each other to fine-tune their velocity. The particles share information about the best positions they have found, helping the swarm converge on an optimal solution. This approach is practical in solving complex computational problems.

Numerous studies emphasize the effectiveness of Particle Swarm Optimization (PSO) in tuning PID controllers, consistently outperforming traditional methods like Ziegler-Nichols (ZN). Klemen Deželak et al. [7] demonstrated PSO's superiority in photovoltaic power plants by reducing overshoot and simplifying implementation. Arti Saxena et al. [8] [9] highlighted FOPID-PSO's enhanced performance compared to fuzzy and ZN-PID methods in high-performance drilling machines, offering better control and stability. Additionally, Saxena and Y.M. Dubey [10] confirmed PSO's effectiveness in overcoming the limitations of traditional tuning by ensuring more precise parameter tracking. Wu [11] proposed Interactive Evolution PSO (IEPSO), an advanced algorithm surpassing Linear Weight Decrease PSO and Stochastic PSO in efficiency and control precision. For Automatic Voltage Regulators (AVR) and electro-hydraulic servo systems, Kansit [12] and Samakwong [13] demonstrated PSO's capability to minimize overshoot and enhance stability compared to ZN and Genetic Algorithms (GA). Zahratul Laily Edaris et al. [14] validated PSO's application in single-tank water level systems, achieving optimal performance where ZN methods struggled. PSO's versatility extends to MIMO systems, as shown by Taeib and Chaari [15], who achieved improved responsiveness and control. Earlier investigations by Yadav et al. [16] and Kushwah & Patra [17] confirmed PSO's advantages in improving steady-state responses, minimizing overshoot, and reducing rise and settling times in DC motor systems. These findings collectively establish PSO as a robust and adaptable solution for PID controller optimization across diverse applications. The application of Particle Swarm Optimization (PSO) in PID controller tuning has demonstrated superior performance across diverse systems compared to traditional methods. Hashim et al. [18] successfully applied PSO in a micro-EDM model, reducing overshoot and settling time for precise positioning. Kanojiya and Meshram [19] confirmed that PI-PSO provided the most suitable transient response for DC motor tuning compared to ZN and modified ZN methods. Similarly, Milani et al. [20] proposed a PID-PSO-ZN approach for brushless DC motors, yielding enhanced response characteristics.

Table 1. Review of Previous studies related to ZN-PID/FOPID and PSO-PID/FOPID for various

References	System	Controller/ Algorithm	Rise Time (t_r)	Peak Time (t_p)	Settling Time (t_s)	Peak Overshoot (M_p)(%)
Edaris and Rahman [13]	Water Tank	ZN-PID	0.308	-	-	55.1
		PSO-PID	6.3	-	-	0
Kansit and Assawinchaichote [33]	Automatic Voltage Regulator	ZN	2.232	-	2.950	-
		PSO	0.536	-	2.561	-
Samakwong & Assawinchaichote [11]	Electro-hydraulic Servo Valve System	ZN	0.386	-	10.2	58.3
		PSO	0.282	-	4.64	1.23
A. Yadav et al. [16]	DC Motor	ZN-PID	0.0813	0.2290	2.3630	74.40
		PSO-PID	0.3437	1.0998	7.1901	9.977
Kanojiya & Meshram [19]	DC Motor	PID-ZN	0.312	-	2.27	27.9
		PI-PSO	0.3907	-	0.6467	0.042
Hashim et al. [18]	Micro-EDM	PSO-PI	0.0140	1.0412	0.0380	-
Bassi et al. [22]	D.C. Motor	ZN	0.307	-	3.44	28.1
		PSO	0.418	-	3.17	17.4
Kumar et al. [23]	Drilling Machine	ZN-PID	0.223	0.4	2.7	43
		PSO-PID	0.17	0.2	1.4	18
Jain et al. [32]	DC Motor	PSO-PID	$2.82\, e^{-5}$	-	-	6.89
		PSO-FOPID	$7.0\, e^{-5}$	-	-	2
Lahoty et al. [34]	Drilling Machine	ZN-PID	0.15	0.364	1.61	41.70
		PSO-PID	0.113	0.282	2.560	36.200
Saxena et al. [8], [10]	Drilling Machine	ZN-PID	0.174	0.857	1.28	5.55
		PSO-PID	0.114	0.223	0.836	6.404
		ZN-FOPID	0.155	0.381	0.746	22.400
		PSO-FOPID	0.175	0.224	0.823	2.440
M. Zamani et al. [35]	AVR	PID	-	-	-	88
		PSO-FOPID	-	-	-	20
Sundaravadivu et al. [32]	Spherical Tank (liquid level control)	PID	-	-	60	20.1
		FOPID	-	-	38.1	0
Vishal et al. [36]	DC Motor	PID	0.175		0.53	9
		FOPID	0.2065		0.3	4
Rinku et al. [37]	DC Motor	PID	-	1.9937	5.5025	29.5939
		FOPID	-	2.1774	5.0176	15.2073

Simulations by Solihin et al. [21] and Bassi et al. [22] revealed that PSO-tuned PID controllers significantly improved system stability and delivered robust transient responses in third-order DC motor models. In high-performance drilling systems, Kumar et al. [23] highlighted PSO's ability to minimize Integral of Absolute Error (IAE) and overshoot compared to ZN tuning. Thomas & Poongodi [24] emphasized the efficiency of genetic algorithms in fine-tuning PID constants, demonstrating improved settling times and reduced errors. Further advancements include fuzzy-PSO and PID-PSO methods, as Boumediène Allaoua et al. [25] demonstrated in DC motor speed control, where PID-PSO outperformed fuzzy-PSO in reducing rise time and overshoot. Oonsivilai and Marungsri [26] confirmed the efficiency of PSO-tuned power system stabilizers (PSS) over traditional ZN methods. For time-delay systems, Haber et al. [27] highlighted that PSO outperformed older methods like Cohen-Coon and ZN by reducing overshoot and the Integral of Time-weighted Absolute Error (ITAE). Haber et al. [28] investigated PID control under high-performance machine (HPM) conditions for drilling processes, emphasizing its efficacy in minimizing overshoot, maintaining cutting force stability, protecting equipment, and enhancing productivity through reduced cycle times. Advanced approaches, such as the '0.618' method within Simplex PSO, introduced by Li et al., [29] achieved improved convergence efficiency and dynamic quality. Moreover, Nayak and Singh [30] validated PSO's scalability in addressing non-linear optimization challenges, underscoring its efficacy in optimizing PID parameters for stable and efficient systems. These studies affirm PSO's robust adaptability and efficiency in optimizing PID controllers for various applications. Overall, employing PID controllers is crucial for enhancing system stability and performance, with PSO algorithms proving this.

An overview of many former written works tells us that many researchers have optimized the transient response of DC servomotor utilizing the PSO Algorithm and conventional ZN method. The former work undertaker for tuning the PID controller of DC servomotor by Yadav et al. [16] resulted in ZN-PID and PSO-PID having an overshoot of 74.40% and 9.977%, respectively. ZN-PID and PSO-PID have a very high settling time, i.e., 2.3630 and 7.1901, respectively, according to Kumar and Babu's [31] research, the ZN method has a high overshoot value of 61.74 and a settling time of nearly 5.0139 sec. The PSO-PID reduces the system overshoot and settling time to 3 and 0.56 seconds, respectively. Ganesh et al. [32] tuned a PID-controlled DC servomotor and concluded that with no load, it has an overshoot of about 28.5% and a load of 26.8%. This observation has motivated the author to refine the system to reduce overshoot, reduce settling time, and enhance its response efficiency. Table 1 represents the previous work. Table 1 reveals that applying ZN and PSO to the same system yields a superior response from the PSO algorithm. A PID controller tuned by AI-based techniques gives better optimization than conventional methods. Therefore, we strive to enhance the response to the optimal level. Herein, we have considered the ZN method and PSO algorithm for optimizing the parameters of the DC servomotor.

Contribution to the current work

The primary aggregate of work done is given by:

- Optimize the ZN-PID controller values (K_p=5.7960, K_i=20.1199, K_d=0.4174) for the DC servomotor system.
- Optimize the ZN-FOPID controller values (K_p=5.7960, K_i=20.1199, K_d =0.4174 ,λ =0.925, μ= 1.225) for DC servomotor system.
- Optimize the PSO-PID controller values (K_p=1.2343, K_i=3.5715, K_d =3.0049) for the DC servomotor system.
- Optimize the PSO-FOPID controller values (K_p=1.2343, K_i=3.5715, K_d =3.0049, λ =0.92, μ= 1) for DC servomotor system.
- Compare the step response of the DC servomotor tuned by ZN-PID, ZN-FOPID, PSO-PID, and PSO-FOPID.
- The results are shown in Table 5. It was found that PSO gives a better response to less rise time (t_r=0.0392), less settling time (t_s=0.0605), and optimized peak overshoot (M_p =1.92%). This signifies that the PSO-FOPID-controlled system shows a faster and more refined response.

The novelty of this study lies in integrating Particle Swarm Optimization (PSO) to optimize PID and FOPID controllers in armature-controlled DC servomotors. This research advances previous work by comparing PSO with Ziegler-Nichols (ZN), achieving superior transient responses and extending PSO optimization to FOPID parameters for enhanced stability and efficiency in industrial applications.

METHOD

Modeling of DC servomotor

Electric motors that are specifically engineered for precise control of speed, torque, or angular position are known as DC servo motors. Based on the principles of electromagnetism, rotational motion is generated by the interplay of current-carrying conductors and magnetic fields. To describe its dynamic behavior mathematically, engineers often use a transfer function. Understanding the transfer function of a DC servo motor is crucial for designing and optimizing control systems in various industries, including robotics, automation, and precision manufacturing. Engineers use it to predict and adjust the motor's response characteristics, ensuring precise and stable operation in demanding applications.

In summary, the transfer function of a DC servo motor provides a mathematical model that engineers use to analyze, design, and control its dynamic behavior, enabling accurate and responsive motion control in real-world applications. In practical applications, DC servo motors are often used in closed-loop control systems. A feedback device, like an encoder, constantly tracks the motor's precise location or velocity. A controller takes this feedback signal and compares it to a reference input; the result is an error signal. This study will focus on the DC motor with armature control. To keep the torque constant, this motor type adjusts the armature current while keeping the field current constant.

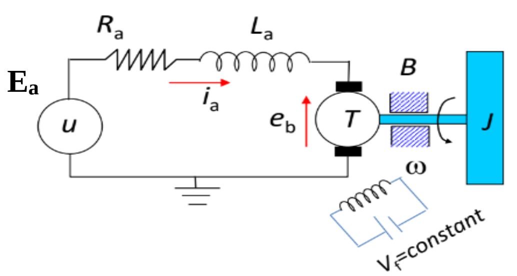

Figure 1. DC motor armature control schematic

The rotor's rotation makes a 90-degree angle with the stationary field. The equation (1) shows that the voltage produced across its terminal e_b is proportional to the speed.

$$\omega = \frac{d\theta}{dt}$$

$$e_b = K_b \frac{d\theta}{dt} \quad (1)$$

Where back EMF constant is K_b. The mathematical model guiding the armature loop is represented by the equation (2).

$$E_a = L_a \frac{di_a}{d_t} + R_a i_a + e_b \quad (2)$$

Since motor torque (T_M) is proportional to the armature current (i_a) as indicated by equation (3), where (i_a) is the armature current.

$$T_M = K_t i_a \quad (3)$$

Equation (4) depicts the dynamic equation of motor torque with coefficient of friction (f) and moment of inertia (J).

$$the\ T_M = J\frac{d^2\theta}{dt^2} + \frac{d\theta}{dt} \quad (4)$$

Since $\omega(s) = s\theta(s)$. As a result, the transfer function of the DC servomotor with speed regulation is:

$$\frac{\theta(s)}{E_a(s)} = \frac{K_t}{s\,[(R + L_a s) + (Js + B) + (K_t K_b)]} \quad (5)$$

Figure 2 shows the schematic representation of the DC servomotor. Table 2 gives the values of different variables for DC motor modeling. A straightforward mathematical interrelation between the angular shaft θ(s) and angular voltage E_a(s) for the DC can be deduced from physical laws, which is shown by Equation (5).

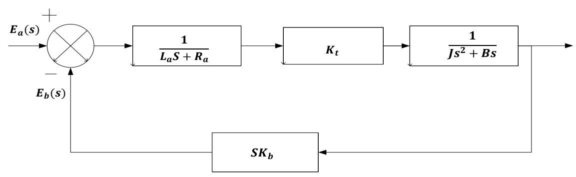

Figure 2. Schematic Representation of a DC Servomotor

Table 2. Model Parameters Values for DC Motor Modeling[38]

Parameters	Variable	Value
Motor Torque Constant	K_t	0.0924
Armature Resistance	R_a	2.518
Inductance of Armature Winding	L_a	0.028
Equivalent moment of inertia	J	0.003
Equivalent friction coefficient	B	0.0005
Back EMF constant	K_b	0.0924

Hence, the overall transfer function is shown by equation (6) for the model parameters considered.

$$\frac{\theta\,(s)}{E_a(s)} = \frac{0{,}0924}{0{,}000085\ s^3 + 0{,}007568 s^2 + 0{,}009796 s} \qquad (6)$$

PID Controller

Industries primarily utilize PID controllers due to their ability to determine fewer variables. PID tuning is a technique that calculates the proportional, integral, and derivate gain for the PID controller to achieve the desired result. PID controllers compute an inaccuracy and attempt to reduce it by controlling the input of the system on which it is used. It modifies the system by minimizing its overshoot and settling time and can remove the steady state offset by the integral controller. It contains three controllers: proportional, integral, and derivative [39]. Figure 3 shows the block diagram of the PID controller.

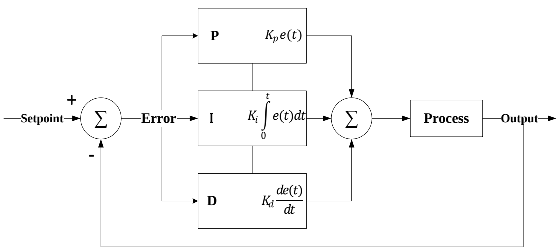

Figure 3. Schematic Representation of PID controller

The PID controller equation is shown by equation (7) as follows:

$$L(s) = K_p + \frac{K_i}{s} + K_d s \qquad (7)$$

Where, L(s) PID controller transfer function K_p= Gain of Proportional Controller K_i = Gain of Integral Controller K_d = Gain of Derivative Controller

FOPID Controller

In 1994, Podlubny published a study introducing the fraction PID controller [40]. A fractional-order system was considered, and it was found that the FOPID controller can handle one well enough. When compared to traditional PID, FOPID represents the most recent advancement. In its simplest form, the word FOPID refers to a parameter associated with the optimal changing coefficient. FOPID has eliminated the stability and robustness problems that plagued classical PID. FOPID achieves better outcomes for the higher-order system than PID in terms of low overshoot and fast settling time. The iso-damping property is achieved in FOPID, which significantly aids in enhanced performance. The system's dynamics are modulated via the P, I, D, λ (lambda), and μ (mu) coefficients. We can establish an estimation model by reducing the number of open control parameters and then optimizing the parameters of the FOPID controller through numerical calculation.

The mathematical form of the FOPID controller dynamics is given in equation (8).

$$P(s) = K_p + \frac{K_i}{s^\lambda} + K_d S^\mu \qquad (8)$$

Where P(s)-FOPID controller transfer function, λ- integration order, and μ-derivative order.

Among the many types of fractional controllers, the classic PID controller is a subset in which λ = μ= 1. Constant movement across the PID plane replaces the need to "bounce" between four distinct locations. In this case, we consider just fractions ranging from 0 to 2. When the controller parameters are optimized, the FOPID may provide better overall performance. However, when tweaking a larger number of parameters, the corresponding optimization problem may become more challenging to manage. Expanding a precise strategy for FOPID optimization to achieve better overall performance is motivating.

ZN Tuning Method

The ZN tuning method applies a heuristic approach for PID controller adjustments. Ziegler [37] and Nichols [41] introduced this technique. During its design, the D (derivative) gain is set to zero, and the I (integral) gain is set to infinity. The critical gain (K_{cr}) and critical frequency (W_{cr}) form the basis for the ZN tuning technique based on trial and error. The design criterion in this method is the damping ratio at one-quarter amplitude. The ZN technique has two significant flaws: It takes a long time and can't be employed with plants that use open-loop systems because of their inherent instability.

Ziegler-Nichols Method for tuning of PID/FOPID Controller

Tuning of the PID controller by the ZN method is one of the traditional methods. It was given by Ziegler and Nichols, who discussed the frequency and step response methods. This paper will study the step response method for tuning the PID/FOPID controller. The benefit of using this method is that it offers easy mathematical calculations. Tuning the PID/FOPID controller by the ZN method (K_p =5.7960, T_i =0.2881, T_d=0.0720, λ =0.925, μ= 1.225) was shown in Table 3.

The block diagram of the optimized PID/FOPID-tuned DC motor is shown in Figure 4.

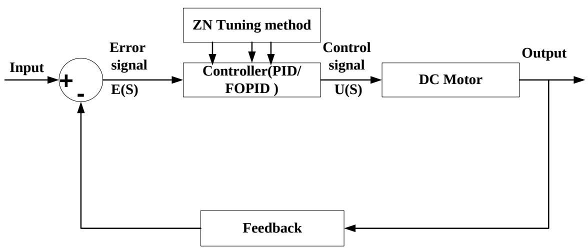

Figure 4. PID/FOPID driven DC motor with a ZN tuning

PSO Tuning Method

Optimization algorithms (PSO) maximize the utility of the PID controller for peak system efficiency. In 1965, scientists Dr. Eberhart and Dr. Kennedy created guidelines for PSO, a form of computational optimization inspired by the cooperative behaviors of animals like flocking birds. Non-linear problem-solving may be a good fit for the PSO [7]. Recently, there has been a significant surge in the deployment of PSOs in this field. PSO has opted for a high-quality enhancement metric that is easy to implement and cheap to compute.

PSO Algorithm for tuning of PID/FOPID Controller

The PSO algorithm is a metaheuristic algorithm. PSO searches for the best possible result by updating iterations. PSO resolves the problem by having a population (swarm) of candidate solutions (particles). The movement of each particle is controlled by its local best-known position. When any optimal control variable of any particle surpasses the search space (the range in which the algorithm evaluates the optimal control variable), the value will be reinitialized. The PSO algorithm is easy to apply, and few parameters are used. Suppose a flock of birds is arbitrarily flying and searching for food in a surrounding area. There is only one piece of food in the surrounding area. The birds are unaware of the food's location, but they can estimate its distance with each iteration. In PSO, we will consider the bird.

Table 3. ZN FOPID Tuning Values

Gain Coefficients Values	K_p	$K_p = K_p/T_i$	$K_d = K_p * T_d$	Lamda (λ)	Mu (μ)
				0.94	1.2
				0.91	1.2
	5.796	**20.119**	**0.417**	0.93	1.15
				0.925	1.22
				0.925	**1.225**

That is nearest to the food. If one bird out of all the birds discovers the appropriate path, all the other birds will follow suit. The PSO algorithmic procedure follows these steps to complete the iteration and identify the optimal tuning:

Start

1) Set the initial positions and velocities of the particles to a random distribution (x_i, y_j) and v_p for all iterative sample values.
2) Verify if every particle meets the required standard.
   $x_i \geq r_d$ (All random samples should be greater than or equal to r_d, where r_d is the threshold)
   y_j € r_d (within the boundary of the sample size, each repetition of the random sample should be equally spaced)
   Within the sample size, each iterative sample value should have a different velocity, denoted as

$v_p \leftrightarrow x_i € r_d$

3) Mark the current value of the threshold to get stored

r_d = stored threshold

R_{rd} = new reference

4) Check if the condition that follows the update is satisfied by comparing the current threshold value with the next iterative particle sample

$r_d \leq R_{rd}$

R_{rd} determines the stored threshold.

If else

$R_{rd} + 1$ = new threshold

Compare and make a new threshold

$R_{rd} + 1 \leq R_{rd} + 2$

Continue doing so until the specified number of iterations has been reached.

5) Update after comparison
6) Do it again if the conditions are still unsatisfactory (Step 3). The end process will be completed once all requirements have been satisfied.

The PSO Algorithm determines the minimal value of the fitness function for 50 iterations. Utilizing the ZN method and PSO algorithm for tuning the PID/FOPID controller for the DC servomotor, the controller gains (K_p,K_i,K_d,λ, μ) are shown in Table 4. Using equation (9)[36], we can determine that the fitness function has minimal values at these controller gain settings at 50 iterations:

$$F = (1 - e^{-0.5}) * (M_P + E_{ss}) + e^{-0.5} * (t_s - t_r) \quad (9)$$

F = 0.2115

Were, F – fitness function,

M_p − *Peak overshoot*, t_s − *setting time*, t_r − *rise time*, *Ess* − *steady state erorr*

Table 4. PSO PID/FOPID Tuning Values

Gain Coefficients Values	K_p	$K_i = K_p / T_i$	$K_d = K_p * T_d$	Lambda (λ)	mu(μ)
				0.94	1
				0.94	1.1
	1.2343	3.5715	3.0049	0.94	0.98
				0.92	0.92
				0.92	**1**

The block diagram of PSO optimized PID/FOPID-tuned DC motor is shown in Figure 5.

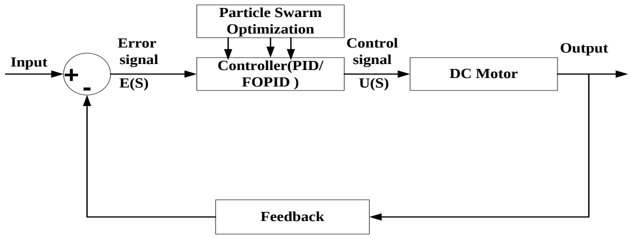

Fig. 5 PSO tuned PID/FOPID controlled DC motor.

RESULTS AND DISCUSSION

In this paper, we have applied the PSO for tuning the PID/FOPID controller for the DC servomotor system. To obtain the most favorable condition, many iterations are performed. We have taken the 50 iterations and a population size of 100 to calculate the best estimate of the provided factor. Table 5 shows that the conventional Ziegler-Nichols method gives a long rise time, settling time, and high overshoot. Hence, we can get a better response by the PSO algorithm by decreasing the rise time and settling time and less overshoot.

Table 5. Comparison of Transient Performance Parameter

References	System	Controller/ Algorithm	Rise Time_ t_r	Settling Time_ t_s	Peak Overshoot _ M_p (%)
Proposed	DC Motor	Closed Loop	0.337	6.53	58.5
		ZN -PID	0.103	3.48	70.5
		ZN-FOPID	0.116	4.07	46
		PSO -PID	**0.0363**	**2.68**	**14.3**
		PSO-FOPID	**0.0392**	**0.0605**	**1.92**
Yadav et al. [11]	DC Motor	ZN-PID	0.0813	2.3630	74.40
		PSO-PID	0.3437	7.1901	9.977
Kanojiya & Meshram [14]	DC Motor	PID-ZN	0.312	2.27	27.9
		PI-PSO	0.3907	0.6467	0.042
Bassi et al. [17]	DC Motor	ZN-PID	0.307	3.44	28.1
		PSO-PID	0.418	3.17	17.4

In the ZN method, the system requires high maintenance because of high overshoot, which tuning using PSO reduces. Results show that the proposed controller design is reliable and responds better to a wide range of process information. The rise time is less by the PSO algorithm than the ZN method, which will help the DC motor respond fast, making the system fast. The rise time is also less, making the system faster and getting the output in less time.

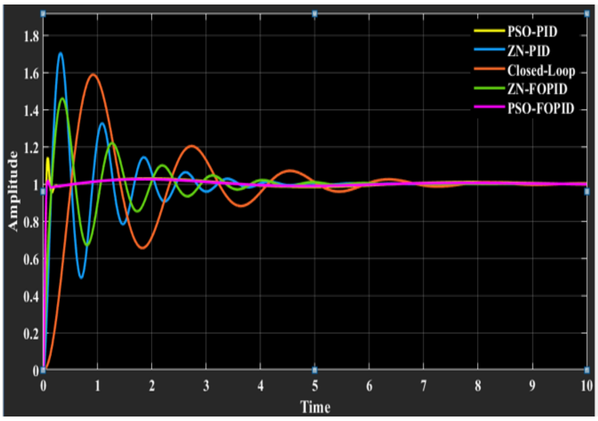

Fig 6 Step response of DC motor without optimization, with ZN-PID, ZN-FOPID,

PSO-PID and PSO-FOPID optimization

The two key pieces of information are laid out in Table 5, and we'll analyze them in greater depth below:

- The proposed PSO-FOPID controlled structure outperforms the other methods listed in Table 5 in terms of response time ($\mathbf{t_r}$=0.0392 sec), (t_s**=0.0605),** and overshoot ($\mathbf{M_p}$ =1.92%).
- PSO-PID tuned proposed system provides optimal outcome looking towards rise time ($\mathbf{t_r}$=0.0363 sec and moderate overshoot ($\mathbf{M_p}$=14.3%) at the cost of high settling time ($\boldsymbol{t_s}$ =2.68 sec).

The suggested PSO-FOPID system exhibits a desirable controlled overshoot in practice. Oscillations and vibrations are inherently brought into any system, however, with the minimum overshoot system, these effects are mitigated, leading to improved performance.

Aligned with prior studies, this research applies Particle Swarm Optimization (PSO) for tuning DC servomotor control systems and extends its scope by incorporating Fractional Order PID (FOPID) tuning to enhance efficiency. Deželak et al. [7] demonstrated PSO's effectiveness in reducing overshoot for PI controllers in photovoltaic systems, although FOPID tuning was not explored. Similarly, Hashim et al. [18] explored PSO in micro-EDM systems, achieving significant overshoot reduction, but their study was limited to PI control without FOPID comparisons. Saxena et al. [9] investigated FOPID-PSO, revealing promising results in high-performance drilling machines, though with longer settling times than observed in this study. Thus, this research not only achieves superior results in FOPID tuning but also broadens the application of PSO, contributing significantly to the development of high-precision control systems for diverse industrial applications.

This study highlights the advantages of Particle Swarm Optimization (PSO) in tuning Fractional Order PID (FOPID) controllers, offering a more stable and efficient solution than the Ziegler-Nichols (ZN) method. Simulations reveal PSO's superior performance, with a rise time of 0.0392 seconds, a settling time of 0.0605 seconds, and an overshoot of 1.92%. The direct comparison between ZN and PSO provides quantitative evidence of PSO's effectiveness. Additionally, the iterative approach with 50 iterations and a population size of 100 ensures optimal tuning and robust results. These findings establish this study as a key contribution to high-precision control systems for industrial applications.

Although the PSO-FOPID method in this study demonstrates promising results, several limitations should be acknowledged. The focus on armature-controlled DC servomotors limits generalizability to other control systems, and simulation-based findings require validation on physical hardware to ensure industrial applicability. Additionally, the method has not yet been tested on more complex systems, and long-term studies are needed to assess its reliability under various operational conditions. Nevertheless, the method holds significant potential for improving precision and efficiency in industrial automation, including applications in robotics and manufacturing. It also offers the benefit of reducing maintenance costs and extending the device's lifespan. Further development, including integration with other control techniques, could expand its utility across a broader range of industrial needs.

LIMITATION

Although the PSO-FOPID method demonstrated significant performance improvements for DC servomotors, the research has several limitations. The study focused exclusively on armature-controlled DC servomotors, limiting its applicability to other motor types and control systems. Furthermore, the results were derived from simulation-based analyses, which may not fully replicate real-world conditions. Hardware validation is necessary to confirm the practicality of these findings. The study also did not explore the integration of other advanced optimization techniques, which could enhance its robustness for diverse industrial applications. Additionally, long-term performance under varying operational conditions was not evaluated, leaving room for further exploration.

CONCLUSION

The research's subject is the tuning of the PID/FOPID controller for the DC servomotor system. Tuning the DC servomotor is crucial since it affects the system's efficiency and reliability. This study proposes the conventional ZN method and the intelligent PSO algorithm for adjusting the PID/FOPID controller. This study has developed two optimization strategies for FOPID tuning, which aim to improve the functionality of DC servo motors. For this reason, the PSO-FOPID proposed controlled system with numerical output (rising time = 0.0392 sec, settling time = 0.0605 sec, peak overshoot = 1.92 percent) from Table 5 determines the optimal route that contributes to the construction of the optimized system. Parameter optimization and reduced overshoot are necessary for practical machinery; these measures dampen system oscillations and vibrations. A shorter settling time and less overshoot were confirmed as causes of the improved transient response. This approach gives a better option for developing the dynamic actions of the control system and reduces the number of possible controller designs. Applying this technique simplifies the design, which was previously a complex system. When compared to tuning the PID controller using traditional methods like the ZN approach, the overall performance of a system with a PSO-tuned PID or FOPID controller is noticeably higher. A comparison of PSO and the traditional ZN approach for identifying FOPID controller readings reveals that PSO provides superior results. This study will aid the industrial sector in releasing a stable system with minimal overshoot, all while improving the other governing factors.

AUTHORS CONTRIBUTION

While conducting the simulation analysis, **VRP** conceived the study and developed the methodology. **AA** provided supervision, developed the theoretical framework, and contributed to the review and editing process. **AS** was responsible for data curation, literature review, and technical validation. R.U. conducted the investigation, formal analysis, and interpretation of the results. **MMD**. Contributed to methodological refinement, comparative analysis, and manuscript review. **AD** was involved in visualization, preparing graphical representations, and finalizing the manuscript for submission. All authors reviewed and approved the final version of the manuscript.

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REFERENCES

[1] M. Pravika, J. Jacob, and K. Paul Joseph, "Design of linear electromechanical actuator for automatic ambulatory Duodopa pump," *Eng. Sci. Technol. an Int. J.*, vol. 31, p. 101056, 2022, https://doi.org/10.1016/j.jestch.2021.09.002.

[2] D. Potnuru, K. Alice Mary, and C. Sai Babu, "Experimental implementation of Flower Pollination Algorithm for speed controller of a BLDC motor," *Ain Shams*

Eng. J., vol. 10, no. 2, pp. 287–295, 2019, https://doi.org/10.1016/j.asej.2018.07.005.

[3] N. G and K. J, “Performance comparison between PID and Fuzzy logic controllers for the hardware implementation of traditional high voltage DC-DC boost converter,” *Heliyon*, vol. 10, no. 17, p. e36750, 2024, https://doi.org/10.1016/j.heliyon.2024.e36750.

[4] F. A. Salem, “Controllers and Control Algorithms : Selection and Time Domain Design Techniques Applied in Mechatronics Systems Design (Review and Research) Part I,” vol. 2, no. May, pp. 160–190, 2013.

[5] S. Panda, B. K. Sahu, and P. K. Mohanty, “Design and performance analysis of PID controller for an automatic voltage regulator system using simplified particle swarm optimization,” *J. Franklin Inst.*, vol. 349, no. 8, pp. 2609–2625, 2012, https://doi.org/10.1016/j.jfranklin.2012.06.008

[6] L. Sharma, V. L. Chellapilla, and P. Chellapilla, “Socio-inspired evolutionary algorithms: a unified framework and survey,” *Soft Comput.*, vol. 27, no. 19, pp. 14127–14156, 2023, https://doi.org/10.1007/s00500-023-07929-z.

[7] K. Deželak, P. Bracinik, K. Sredenšek, and S. Seme, “Proportional-integral controllers performance of a grid-connected solar pv system with particle swarm optimization and ziegler–nichols tuning method,” *Energies*, vol. 14, no. 9, 2021, https://doi.org/10.3390/en14092516.

[8] A. Saxena, Y. M. Dubey, M. Kumar, and A. Saxena, “Performance Comparison of ANFIS, FOPID-PSO and FOPID-Fuzzy Tuning Methodology for Optimizing Response of High-Performance Drilling Machine,” *IETE J. Res.*, vol. 69, no. 6, pp. 3497–3510, 2023, https://doi.org/10.1080/03772063.2021.1933625.

[9] A. Saxena, Y. M. Dubey, and M. Kumar, “PSO and fuzzy based tuning mechanism for optimization of transient response in high-performance drilling machine,” *2020 7th Int. Conf. Signal Process. Integr. Networks, SPIN 2020*, pp. 1147–1152, 2020, https://doi.org/10.1080/03772063.2021.1933625.

[10] A. Saxena and C. Engineering, “A Comparative Analysis of Optimization Algorithms for Self Tuning,” vol. 8, no. 2, pp. 1–6, 2019.

[11] S. Wu, “A PID controller parameter tuning method based on improved PSO,” *Int. J. Adv. Comput. Res.*, vol. 8, no. 34, pp. 41–46, 2018, https://doi.org/10.19101/IJACR.2017.73302.

[12] S. Kansit and W. Assawinchaichote, “Optimization of PID Controller Based on PSOGSA for an Automatic Voltage Regulator System,” *Procedia Comput. Sci.*, vol. 86, no. March, pp. 87–90, 2016, https://doi.org/10.1016/j.procs.2016.05.022.

[13] T. Samakwong and W. Assawinchaichote, “PID Controller Design for Electro-hydraulic Servo Valve System with Genetic Algorithm,” *Procedia Comput. Sci.*, vol. 86, no. March, pp. 91–94, 2016, https://doi.org/10.1016/j.procs.2016.05.023.

[14] Z. L. Edaris and S. Abdul-Rahman, “Performance Comparison Of Pid Tuning By Using Ziegler-Nichols And Particle Swarm Optimization Approaches In A Water Control System,” *Appl. Microbiol. Biotechnol.*, vol. 85, no. 1, p. 6, 2016.

[15] A. Taeib and A. Chaari, “Tuning optimal PID controller,” *Int. J. Model. Identif. Control*, vol. 23, no. 2, pp. 140–147, 2015, https://doi.org/10.1016/j.procs.2016.05.023.

[16] A. I. Y. Adav, D. R. S. U. W. Adhwani, and D. R. A. K. W. Adhwani, “Particle Swarm Optimization Based Intelligent Tuning of PID Controller for DC Servo Motor Control,” vol. 03, no. 15, pp. 3106–3110, 2014.

[17] M. Kushwah and A. Patra, “PID Controller Tuning using Ziegler-Nichols Method for Speed Control of DC Motor,” *Int. J. Sci. Eng. Technol. Res.*, vol. 3, no. 13, pp. 2924–2929, 2014.

[18] N. L. S. Hashim, A. Yahya, T. Andromeda,

M. R. A. Kadir, N. Mahmud, and S. Samion, "Simulation of PSO-PI controller of DC motor in micro-EDM system for biomedical application," *Procedia Eng.*, vol. 41, pp. 805–811, 2012, https://doi.org/10.1016/j.procs.2016.05.023.

[19] R. G. Kanojiya and P. M. Meshram, "Optimal tuning of PI controller for speed control of DC motor drive using particle swarm optimization," *2012 Int. Conf. Adv. Power Convers. Energy Technol. APCET 2012*, no. Dc, 2012, https://doi.org/10.1109/APCET.2012.6302000.

[20] M. M. R. A. Milani, T. Çavdar, and V. F. Aghjehkand, "Particle swarm optimization - Based determination of Ziegler-Nichols parameters for PID controller of brushless DC motors," *INISTA 2012 - Int. Symp. Innov. Intell. Syst. Appl.*, 2012, https://doi.org/10.1109/INISTA.2012.6246984.

[21] M. I. Solihin, L. F. Tack, and M. L. Kean, "Tuning of PID Controller Using Particle Swarm Optimization (PSO)," *Int. J. Adv. Sci. Eng. Inf. Technol.*, vol. 1, no. 4, p. 458, 2011, https://doi.org/10.18517/ijaseit.1.4.93.

[22] Bassi, Mishra, and Omizegba, "Automatic Tuning Of Proportional-Integral-Derivative (Pid) Controller Using Particle Swarm Optimization (Pso) Algorithm," *Int. J. Artif. Intell. Appl.*, vol. 2, no. 4, pp. 25–34, 2011, https://doi.org/10.5121/ijaia.2011.2403.

[23] S. M. GirirajKumar, D. Jayaraj, and A. R. Kishan, "PSO Based Tuning of a PID Controller for a High Performance Drilling Machine," *Int. J. Comput. Appl.*, vol. 1, no. 19, pp. 12–18, 2010, https://doi.org/10.5120/410-607.

[24] N. Thomas and P. Poongodi, "Position Control of DC Motor Using Genetic Algorithm Based PID Controller," vol. II, pp. 1–5, 2009.

[25] B. Allaoua, A. Laoufi, B. Gasbaoui, and A. Abderrahmani, "Neuro-Fuzzy DC motor speed control using particle swarm optimization," *Leonardo Electron. J. Pract. Technol.*, vol. 8, no. 15, pp. 1–18, 2009.

[26] A. Oonsivilai and B. Marungsri, "Optimal PID Tuning of Power System Stabilizer for Multi-machine Power System using Particle Swarm Optimization," *Proc. 12th Wseas Int. Conf. Circuits*, vol. 3, no. 6, pp. 345–350, 2008.

[27] R. E. Haber, R. Haber-Haber, R. M. Del Toro, and J. R. Alique, "Using simulated annealing for optimal tuning of a PID controller for time-delay systems. An application to a high-performance drilling process," *Lect. Notes Comput. Sci. (including Subser. Lect. Notes Artif. Intell. Lect. Notes Bioinformatics)*, vol. 4507 LNCS, pp. 1155–1162, 2007, https://doi.org/10.1007/978-3-540-73007-1_140.

[28] R. Haber-Haber, R. Haber, M. Schmittdiel, and R. M. del Toro, "A classic solution for the control of a high-performance drilling process," *Int. J. Mach. Tools Manuf.*, vol. 47, no. 15, pp. 2290–2297, 2007, https://doi.org/10.1016/j.ijmachtools.2007.06.007.

[29] J. min Li, Y. C. Liou, and L. jun Zhu, "Optimization of PID parameters with an improved simplex PSO," *J. Inequalities Appl.*, vol. 2015, no. 1, 2015, https://doi.org/10.1186/s13660-015-0785-2.

[30] S. J. D. V. R. Panse, N. S. Kokode, A. N. Yerpude, "Luminescence Investigation of trivalent Dy and Tb doped KAlPO4 Cl phosphor for solid state lighting," *Int. J. Photonics Opt. Technol.*, pp. 21–25, 2016.

[31] P. R. Kumar, A. Pradesh, V. N. Babu, and A. Pradesh, "Position control of servo systems using PID controller tuning with soft computing optimization techniques," vol. 3, no. 11, pp. 976–980, 2014.

[32] C. Ganesh, B. Abhi, V. P. Anand, S. Aranvind, R. Nandhini, and S. K. Patnaik, "DC Position Control System - Determination of Parameters and Significance on System Dynamics," *ACEEE Int. J. Electr. Power Eng.*, vol. 3, no. 1, pp. 1–5, 2012, [Online]. Available: http://hal.archives-ouvertes.fr/docs/00/74/68/91/PDF/8

2.pdf
[33] S. J. D. v. r. Panse, N. S. Kokode, "Preparation, characterization and luminescent properties of LiBO 2 : Tb 3 + green emitting phosphor for solid state lighting," vol. 8, no. December, pp. 4–6, 2018.
[34] Z. Yang, Z. Zhao, Y. Wen, and Y. Wang, " ChemInform Abstract: Structure and Luminescence Properties of Bi 3+ Activated Ca 12 Al 14 O 32 Cl 2 Phosphors. ," *ChemInform*, vol. 44, no. 25, pp. 1542–1546, 2013, https://doi.org/10.1002/chin.201325005.
[35] M. Zamani, M. Karimi-Ghartemani, N. Sadati, and M. Parniani, "Design of a fractional order PID controller for an AVR using particle swarm optimization," *Control Eng. Pract.*, vol. 17, no. 12, pp. 1380–1387, 2009, https://doi.org/10.1016/j.conengprac.2009.07.005.
[36] V. R. Panse, N. S. Kokode, and S. J. Dhoble, "Tb3+ doped Sr2(BO3)Cl green emitting phosphor for solid state lighting," *Adv. Mater. Lett.*, vol. 5, no. 10, pp. 604–610, 2014, https://doi.org/10.5185/amlett.2014.amwc432.
[37] R. Singhal, S. Padhee, and G. Kaur, "Design of Fractional Order PID Controller for Speed Control of DC Motor," *Int. J. Sci. Res. Publ.*, vol. 2, no. 6, pp. 1–8, 2012.
[38] A. N. Yerpude, V. V Shimde, V. R. Anse, S. J. Dhoble, and N. S. Kokode, "Luminescence Properties Of Sral2b2o7:Eu3+ Phosphor For Green Lighting Technology," *Int. J. Curr. Eng. Sci. Res.*, vol. 5, no. 1, pp. 28–30, 2018.
[39] B. Allaoua and B. Mebarki, "Intelligent PID DC motor speed control alteration parameters using particle swarm optimization," *Artif. Intell. Resour. Control Autom. Eng.*, no. 14, pp. 3–14, 2012, https://doi.org/10.2174/978160805126711201010003.
[40] P. Shah and S. Agashe, "Review of fractional PID controller," *Mechatronics*, vol. 38, pp. 29–41, 2016, https://doi.org/10.1016/j.mechatronics.2016.06.005.
[41] C. R. A. Silva, V. C. Panuci, M. R. Coutinho, W. A. S. Conceição, and C. M. G. Andrade, "Analysis of the effects of recycling on process control," *Polish J. Chem. Technol.*, vol. 25, no. 2, pp. 43–55, 2023, https://doi.org/10.2478/pjct-2023-0016.