Optimization of PID Controller Parameters for Speed Control of DC Motor Using Firefly and Fminsearch Algorithms

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Abstract:

This research paper presents a comparative study of the performance of two optimization algorithms, namely the Firefly Algorithm (FFA) and Fminsearch, for the PID tuning of a DC motor speed control system. The performance of the two algorithms is evaluated based on the time-domain response of the DC motor speed control system. The Integral of Time multiplied by the Absolute value of the Error (ITAE) is used as the objective function here. The results show that the Fminsearch algorithm outperforms the FFA in terms of the rate of convergence, computation time and settling time. The proposed approach provides an effective and efficient way for the design and tuning of PID controllers in DC motor speed control systems. This study contributes to the ongoing efforts in developing more efficient and reliable control systems for DC motors, which are widely used in various industrial applications.

Keywords: *DC motor, PID control, optimization algorithms, Firefly Algorithm, Fminsearch.*

1. Introduction:

DC motors are widely used in various industrial applications, such as robotics, aerospace, and manufacturing. The performance of the DC motor is highly dependent on the speed control system, which plays a crucial role in maintaining the motor speed at a desired level. The PID controller is a popular control method for DC motor speed control, which provides a simple and effective way of regulating the motor speed.

The design and tuning of the PID controller are critical for achieving the desired performance of the DC motor speed control system. The optimization algorithms have been widely used for the design and tuning of PID controllers, which automate the process of finding the optimal PID parameters that can achieve the desired performance.

In this paper, we present a comparative study of two optimization algorithms, namely the Firefly Algorithm (FFA) [1] and Fminsearch for the PID tuning of a DC motor speed control system. The FFA is a metaheuristic optimization algorithm inspired by the flashing behaviour of fireflies which is effective in solving various optimization problems [2]. Fminsearch is a built-in optimization algorithm in MATLAB, which is widely used for the design and tuning of PID controllers. It is based on Nelder-Mead simplex method [3].

2. Literature Review:

Many studies have been conducted on the design and tuning of PID controllers for DC motor speed control using various optimization algorithms. For example, Ekinci and his colleagues

[4], present a novel approach to optimize the PID controller parameters for DC motor speed control using the Harris Hawks Optimization (HHO) algorithm [5]. The results of the simulations and experiments presented in the paper show that the optimized PID controller using the HHO algorithm provides better performance compared to the conventional PID controller. The paper also demonstrates the robustness of the proposed method against parameter variations and load disturbances.
In another paper, Qi and his colleagues [6], propose a method for tuning digital PID controllers using the particle swarm optimization (PSO) algorithm[7] for a controller area network (CAN)-based DC motor subject to stochastic delays. The PSO algorithm is then presented as a potential solution to the challenges of tuning PID controllers for the system. The proposed method is validated through simulations and experimental results, which demonstrate that the optimized PID controller using the PSO algorithm provides better performance compared to the conventional PID controller.
In their paper, Ibrahim and his colleagues [8] proposes a method to optimize the PID controller parameters of a brushless DC (BLDC) motor using the genetic algorithm (GA) technique [9]. the paper proposes the use of GA as an optimization tool to search for the optimal PID controller parameters. The proposed method uses the fitness function to evaluate the performance of the PID controller, and the GA algorithm to search for the optimal set of controller parameters. The paper presents simulation results that demonstrate the effectiveness of the proposed method in optimizing the PID controller parameters for the BLDC motor. The optimized PID controller provides better performance compared to the conventional PID controller, as measured by the steady-state error, overshoot, and settling time.
In their paper, Pandey and his colleagues [10] propose a new method to design a robust PID controller for a DC motor using the Teaching-Learning Based Optimization (TLBO) [11] algorithm. the paper proposes the use of the TLBO algorithm to search for the optimal set of PID controller parameters that provide robust performance in the face of these uncertainties and disturbances. The paper presents simulation results that demonstrate the effectiveness of the proposed method in designing a robust PID controller for the DC motor. The optimized PID controller provides robust performance in the presence of modelling uncertainties, parameter variations, and external disturbances, as measured by the steady-state error, overshoot, and settling time.

3. Methodology:

The DC motor speed control system using the PID controller is modelled using the transfer functions given below.
The transfer function for the speed control of the DC motor is modelled as follows:

$$G(s) = \frac{K}{Jbs^2 + Js + K} \tag{1}$$

Here,
K= The torque constant
J= The moment of inertia
b=The damping coefficient
The values of the torque constant K, the moment of inertia J and the damping coefficient b are selected as follows –
K=1 N·m/A
J=0.01 kg·m^2

b=0.1 N·s/m
Substituting the values of K, J and B in equation (1) –

$$G(s) = \frac{1}{0.001s^2+0.01s+1} \tag{2}$$

The PID controller is designed using the following transfer function:

$$C(s) = K_p + \frac{K_i}{s} + K_d \tag{3}$$

where K_p, K_i, and K_d are the proportional, integral, and derivative gains of the PID controller, respectively.

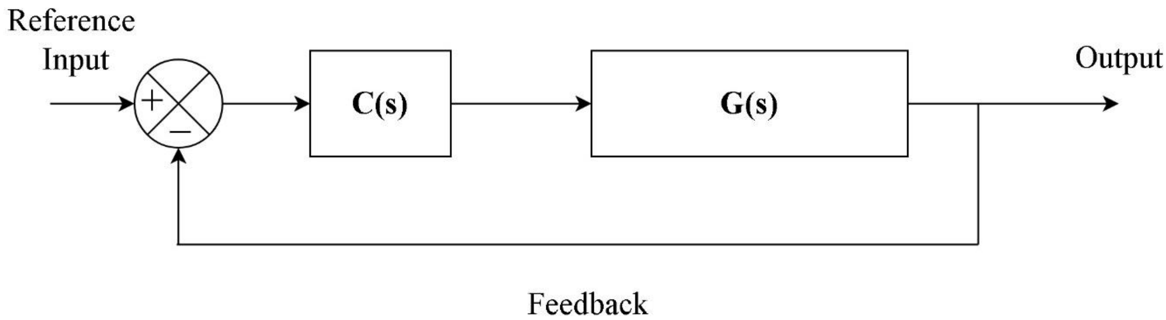

Fig1. Block Diagram of the controller and dc motor arrangement

The arrangement of the controller and the dc motor for the speed control system of the DC motor is given in Fig.1. The objective of the optimization is to find the optimal values of K_p, K_i, and K_d that can minimize the error between the reference speed and the actual speed of the DC motor.
The FFA and Fminsearch algorithms are used for the optimization of the PID controller parameters. The FFA algorithm is implemented using the following steps:

1. Initialize the population of fireflies with random values of K_p, K_i, and K_d
2. Calculate the fitness value of each firefly based on the objective function.
3. Update the light intensity of each firefly based on its fitness value and the distance between the fireflies.
4. Move each firefly towards the brighter fireflies.
5. Evaluate the fitness value of the new population.
6. Repeat steps 3-5 until the stopping criterion is met.

The parameters selected for this work are given below –

- Total number of fireflies=20
- Total number of iterations=600
- Alpha value=0.5
- Beta value=0.2
- Gamma value=1
- The lowest permissible values for the PID tuning parameters=0
- The highest permissible values for the PID tuning parameters=200

The Fminsearch algorithm is implemented using the built-in fminsearch function in MATLAB. The function takes the objective function, initial guess of the parameters, and other parameters as inputs and returns the optimal values of the parameters.
The parameters selected for this work are given below –

- Initial values = 0

- The lowest permissible values for the PID tuning parameters=0
- The highest permissible values for the PID tuning parameters=200

The performance of the two optimization algorithms is evaluated based on the time-domain response of the DC motor speed control system. The time-domain response is analyzed based on the steady-state error, percentage of overshoot, settling time and rise time. The computation times and the convergence plots of both algorithms were also determined and analyzed. The simulation is carried out in MATLAB R2014a in a laptop computer with Intel Core i3-2 GHz CPU and 4 GB RAM.

4. Results and Discussion:

The convergence plots obtained by running both the Fminsearch and FFA are provided in Fig.2.

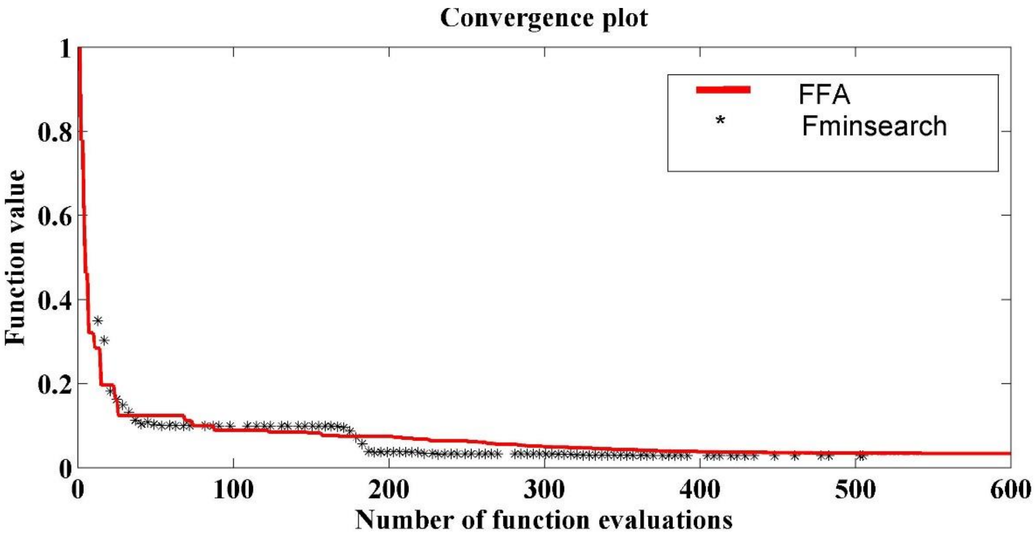

Fig.2. Convergence plots of FFA and Fminsearch

As can be seen from Fig.2, up until near the 200th function evaluation the convergence plots of both the algorithms were approximately the same but at and after the 200th function evaluation there is a sudden dip in the convergence plot of the Fminsearch, which remained nearly constant for the rest of the iterations whereas, near the same function evaluation value of 200, FFA started converging at a constant pace and achieved the same level of error that of the Fminsearch at around 600th iteration. Hence, the Fminsearch algorithm converged quicker than the FFA. ITAE of the Fminsearch algorithm is slightly less and hence better than the FFA.

The values of K_p, K_i & K_d, the final values of the ITAE and the computation time required by both algorithms are shown in Table 1. In terms of computation time, for 600 iterations FFA took around 12 times more computation time than the Fminsearch for the same number of function evaluations so, there is a significant difference in the computation time when both the computation algorithms are compared. Hence, Fminsearch performed better in terms of computation time compared to the FFA.

Table 1: Computed PID tuning parameters and the computation time of the algorithms

Algorithm Name	K_p	K_i	K_d	ITAE	Computation time (Seconds)
Fminsearch	9.8463	199.7961	0.2318	0.0283	28.369460
FFA	13.6032	199.5175	0.3379	0.0338	342.484480

The PID tuning parameters obtained from both the algorithms were set into the PID controller and step response of the system was taken. The step response is shown in Fig.3 and the parameters obtained from the Fig.3 are shown in Table. 2.

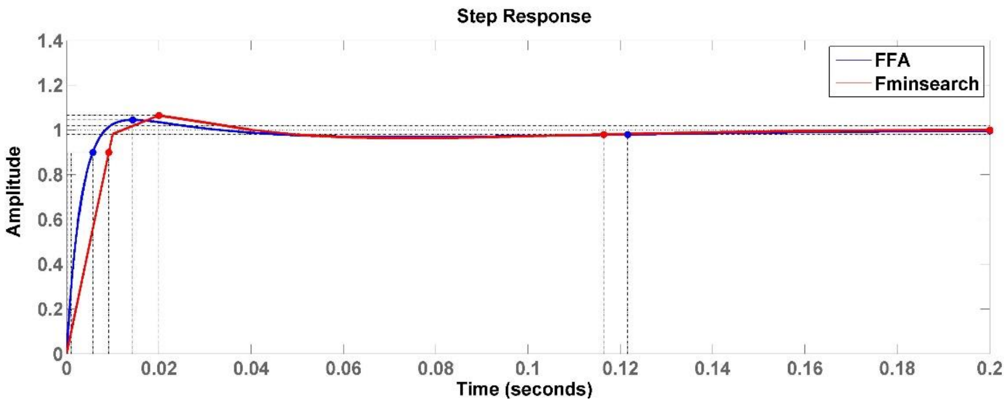

Fig.2. Step responses of the system with FFA and Fminsearch tuned PID parameters

Table 2: The time-domain parameters of the step responses.

PID Name	Percentage of Overshoot (%OS)	Settling Time (t_s)	Rise Time (t_r)	Steady State Value
Fmin-PID	6.48	0.116	0.00814	1
FFA-PID	4.5	0.122	0.00538	1

In terms of the percentage of overshoot, Fminsearch has a higher value of 6.48% compared to FFA which has a value of 4.5%. So, Fminsearch has overshoot of around 1.4 times the overshoot of FFA. A lower overshoot means a better system performance hence, FFA performed better in terms of the percentage of overshoot.

FFA has a settling time of 0.122 seconds while Fminsearch has a settling time of 0.116 seconds. So, the settling time of FFA is about 5% more than that of Fminsearch. Lower settling time is expected from a good system hence, Fminsearch performed better in terms of settling time.

In terms of the rise time, FFA performed better compared to Fminsearch. With a value of 0.00814 seconds, Fminsearch took around 1.5 times more time than the FFA which has a rise time of 0.00538 seconds.

In both cases, the steady state value is 1 which is the same as the reference input of the system hence, both the PID controller performed the same.

Both the rise time and the settling time are important for the evaluation of any system. A longer rise time can lead to a delay in the response of the motor, which may be undesirable in some applications. Similarly, a longer settling time can result in slower tracking of the desired speed, leading to slower response of the motor control system.

However, settling time is usually considered more important in the context of speed control of a DC motor. This is because the steady-state performance of the motor, i.e., how well it maintains a constant speed, is critical for most motor control applications. The settling time determines how quickly the motor reaches its steady-state speed after a change in the control signal, which can affect the overall performance of the control system. Therefore, minimizing the settling time while maintaining a stable system is usually the primary objective in motor speed control applications. Hence, although FFA has a better rise time and percentage of overshoot, Fminsearch performed better in terms of settling time, which is more important in the context of speed control of a DC motor. Hence, Fminsearch performed better compared to FFA for the speed control of a DC motor in terms of time-domain parameters.

5. Conclusion:

In this paper, we have presented a comparative study of two optimization algorithms, namely the FFA and Fminsearch, for the PID tuning of a DC motor speed control system. ITAE is used as the objective function. The performance of the two algorithms is evaluated based on the time-domain response of the DC motor speed control system. The results show that the Fminsearch algorithm outperforms the FFA in terms of the convergence rate, the computation time and the settling time. The proposed approach provides an effective and efficient way for the design and tuning of PID controllers in DC motor speed control systems. This study contributes to the ongoing efforts in developing more efficient and reliable control systems for DC motors, which are widely used in various industrial applications.

Future work includes the investigation of other optimization algorithms and their performance for PID tuning of DC motor speed control systems. The effects of various disturbances and uncertainties on the performance of the optimized controllers can also be studied. Finally, the proposed approach can be extended to other types of motors and control systems.

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