Optimal Control of DC motor using Grey Wolf Optimizer Algorithm

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ABSTRACT: Adjusting PID controller parameters in DC motors is a significant problem in control field. To solve this problem, a new optimized algorithm, Grey Wolf Optimizer Algorithm, is utilized and designed for DC Motor drive to find the global optimum solution in search space. The proposed controller can be used to optimal tuning of proportional-integral-derivative (PID) controller parameters. The proposed technique has been compared by PSO algorithm and the results showed that the proposed algorithm is proper in developing the speed loop response stability, the steady state error is reduced, the rising time is perfected and the disturbances do not affect the performances of driving motor with no overtaking. The DC Motor Scheduling Grey Wolf Optimizer based PID controller is modeled in MATLAB environment.

Keywords: Grey Wolf Optimizer, PID controller, DC motor, Parameter Optimization.

1. INTRODUCTION

The expansion of high performance motor drives is principal in industrial as well as other purpose applications like electric trains, robotics, steel rolling mills, etc. Basically, a high performance motor drive system should have high speed command tracking and load adjusting response for the considered purposes. DC motor drives have some important advances, such as: their simplicity, high reliabilities ease of application, flexibilities have long been a main instrument for home appliances, industrial applications and robot manipulators where speed and position control of motor are required. The complexity of DC drives with a single power conversion from AC to DC is low. DC motors are also more superior to that of AC motors about the speed torque characteristics. DC motors supply supreme control of speed for acceleration and deceleration. DC drives are normally cheap for most horsepower ratings. DC motors have a long tradition of use as tunable speed machines and a wide range of options have perused for this purpose.

In all applications, the motor drive should be accurately controlled to give the desired performance. There are a great deal works for goal to control the speed of DC motor to execute one variety of tasks of several conventional and numeric controller types like: proportional integral derivative (PID), Fuzzy Logic Controller (FLC) or the combination between them: Fuzzy-Neural Networks, Fuzzy-Genetic Algorithm, Fuzzy-Ants Colony, Fuzzy-Swarm, etc(D.B. Fogel, 2006).

The PID controller operates the large share of the control system in the world. It has been reported that more than 95% of the industrial controllers applications are of PID type as no other controller match the clear functionality, simplicity, ease of use and applicability offered by the PID controller(J.G. Zigelor and N.B. Nichols, 1942).(L. Zhang, 2004).

PID controllers can be adjusted with different ways such as: hand tuning Ziegler Nichols, Cohen-coon tuning and Z-N step response, but these methods have some restrictions (Neenu Thomas, 2009). In practice, parameters adjusting are applied by some expert humans by utilizing a trial and error approach and some practical rules; this perform makes the high cost and difficult activity. Optimization Algorithms like GA, PSO, etc. have proved their efficiency in giving good results by developing the steady states characteristics and performance indices.

In this paper, Grey Wolf Optimizer is employed as a new optimization algorithm for optimally designing the PID controller in a DC motor and then the results are compared by PSO algorithm as a renowned optimization algorithm. The main purpose is to use optimal methods include GWO and PSO to design a suitable controller for DC motors. Afterwards, a comparison between these two methods will be illustrated the best method. Output speed stability in DC motors is the most significant factor. Particle Swarm Optimization is a popular renowned algorithm which is
utilized in different optimization problems and is given good result for more problems (Rubaai A., Kotaru R., 2000)(Lin F. J. et al., 1999). Grey Wolf Optimizer (GWO) algorithm is a new optimization method which is employed to solve optimization problems of different varies (S. Mirjalili et al., 2014). Like other heuristic algorithms in the area of evolutionary computation, GWO has not required to the gradient of the function in its optimization process. GWO a mathematical model and the computer simulation which mimics the leadership hierarchy and hunting mechanism of grey wolves in nature. This research has been organized as below: Section 2 the model of linear DC motor is explained; afterwards, the motor and the controller diagram are shown. In section 3, the particle swarm optimization algorithm is reviewed. Section 4, illustrates the new Grey Wolf Optimizer. In section 5 designing the PID controller optimally for a linear DC motor is shown; applying of the described methods to the motor are also presented in this section. And finally simulation, results and comparisons are presented in section 6 and the paper is concluded in section 7.

2. REVIEW STAGE IN MODEL OF DC MOTOR

Electric circuit model of a DC motor is shown in Fig.1. The rotor and the shaft are assumed to be rigid.

DC motors generate torque directly from DC power supplied to the motor via internal commutation, stationary permanent or electromagnets, and rotating electrical magnets (T.H. Kim et al., 2008). Similar to other electrical machines, torque is produced by the principle of Lorentz force which remarks that any current-carrying conductor placed within an external magnetic field experiences a torque or force known as Lorentz force. Fig.2 shows the equivalent circuit of DC motor with a PID controller.

In this paper, The DC motor has a PID controller which is presented in the below:

$$PID = K_p + \frac{K_i}{s} + K_ds$$

PID control is a simple control approach. This type of controller performs directly on the error signal, which is the difference between the considered and the actual output and produces the actuation signal that drives the plant. In the design of PID controller the amount of $K_i$ is described to reach to a defined error in steady state. In PID controller design, $K_p$, $K_i$ and $K_d$, depended on the closed loop feedback system within the least time is described and needs a long range of trial and error. In practice, generating an ideal PID controller is not possible. Hence, in this paper, getting the best response closer to the ideal state is the purpose. By using a low-pass-filter (LPF) in practical PID controllers as derivation input is significant to noise elimination (Ang K. et al., 2005). The utilized motor parameters are illustrated in the table below:
In the last decades, natural based algorithms have been attention paid to solve optimization problem. Optimization techniques such as: Genetic algorithm, particle swarm optimization, imperialist competitive algorithm are some of these popular methods that have already been employed.

Particle Swarm Optimization (PSO) algorithm is one of the most popular optimization algorithms which has been developed in 1995 by Kennedy and Eberhart. PSO algorithm is inspired by the social behavior of birds flocking and fish schooling (Y. Shi, R. C. Eberhart, 1950). In this approach optimal solution to a mathematical optimization problem is restricted of birds behave in the moment the food pursue, the escape from hunters and the search for mates. In the last years, PSO algorithm has been employed in wide variety of applications ranging from classical mathematical programming problems to scientific optimization problems and highly proprietary engineering (M. Zarringhalami et al., 2010); (S. Panda, and N. Padhy, 2008).

Traditional PSO algorithm performs by an initial population (swarm) of candidate solution (particles). These particles are searched around in the search-space in order to a few definite formulations. The particles searching and their moving are followed up to their own best known position in the search-space and the whole swarm's best known position.

After the particles found the proper positions, these will then come to guide the movements of the other particles. The searching around search-space is repeated and by performing so it is hoped, but not guaranteed, that a satisfactory solution will eventually be detected (M. Zarringhalami et al., 2010); then, the swarm is tuned in order to the following equations:

\[
\begin{align*}
    v_{t+1}^{i} &= w_{t}v_{t}^{i} + c_{1}r_{1}(p_{t}^{i} - x_{t}^{i}) + c_{2}r_{2}(g_{t}^{i} - x_{t}^{i}) \\
    x_{t+1}^{i} &= x_{t}^{i} + v_{t+1}^{i}
\end{align*}
\]

Where, \( n \) is the number of particles, \( w \) is the weighted inertia, \( C1 \) and \( C2 \) are the positive constants, \( r1 \) and \( r2 \) are two random numbers distributed within the range \([0,1]\), \( t \) is the iteration number, \( Pi \) is the best position of the \( ith \) particle and \( gi \) is the best particle among the group members (M. Zarringhalami et al., 2010).

Using eq.2, the particles update their velocity according to their previous velocity and the distances to their current position from both their own best historical position and the best positions of the neighbors in every iteration step, and then they fly to a new position given by (3).

### 3. PARTICLE SWARM OPTIMIZATION

This section summarizes the main steps in gray wolf optimizer (GWO) to optimally tuneing of PID controller in DC motor. Grey wolf (Canis lupus) is a new population based algorithm which is introduced in 2014 by Mirjalili et al (Mirjalili et al, 2014). GWO algorithm inspired by grey wolves. The method mimicked the social hierarchy and hunting behavior of grey wolves. For simulating the leadership hierarchy in GWO algorithm, four groups are defined: alpha, beta, delta, and omega. Furthermore, the three main steps of hunting, searching for prey, encircling prey, and attacking prey, are simulated.

This algorithm requires a number of parameters to be set, namely, initialize alpha, beta, and delta. Number of search agents, Maximum number of iterations, number of sites selected for neighborhood search (out of \( n \) visited sites) and the stopping criterion.

The main steps of grey wolf hunting are as follows:

1. Tracking, chasing, and approaching the victim.
2. Pursuing, encircling, and harassing the victim until it stops moving.
3. Attack towards the victim.

For modeling the social hierarchy of wolves until designing GWO, the fittest solution is considered as the alpha (\( \alpha \)). Accordingly, the second and third best solutions are named beta (\( \beta \)) and delta (\( \delta \)) respectively. The rest of the candidate solutions are considered to be omega (\( \omega \)). The \( x \) wolves follow these three wolves.
Next, for modeling encircling behavior, some equations are considered:

\[ \vec{D} = |\vec{C} \cdot \vec{X}_p(t) - \vec{X}(t)| \]  \hspace{1cm} (4)
\[ \vec{X}(t+1) = \vec{X}_p(t) - \vec{A} \vec{D} \]  \hspace{1cm} (5)

where \( t \) is the current iteration, \( \vec{A} \) and \( \vec{C} \) are coefficient vectors, \( \vec{X}_p(t) \) represents the position vector of the victim.

The vectors \( \vec{A} \) and \( \vec{C} \) can be calculated as below:
\[ \vec{X} = 2\vec{a}_1 \vec{r}_1 - \vec{a} \]  \hspace{1cm} (6)
\[ \vec{C} = 2\vec{r}_2 \]  \hspace{1cm} (7)

where \( \vec{a} \) include are linearly decreased from 2 to 0 over the course of iterations and \( \vec{r}_1 \) and \( \vec{r}_2 \) are random vectors in the range \([0, 1]\).

In GWO, the first three best solutions obtained are saved so far and compel the other search agents (including the omegas) to update their positions due to the position of the best search agents. The following formulas are proposed for this regard.

\[ \vec{D}_a = |\vec{C}_1 \vec{X}_a - \vec{X}| \vec{D}_b = |\vec{C}_2 \vec{X}_b - \vec{X}| \vec{D}_\gamma = |\vec{C}_3 \vec{X}_\gamma - \vec{X}| \]  \hspace{1cm} (8)
\[ \vec{X}_1 = \vec{X}_a - \vec{A}_1 \vec{D}_a \vec{X}_2 = \vec{X}_b - \vec{A}_2 \vec{D}_b \vec{X}_3 = \vec{X}_\gamma - \vec{A}_3 \vec{D}_\gamma \]  \hspace{1cm} (9)
\[ \vec{X}(t+1) = \frac{\vec{X}_1(t) + \vec{X}_2(t) + \vec{X}_3(t)}{3} \]  \hspace{1cm} (10)

The final position would be in a random position within a circle which is defined by the positions of alpha, beta, and delta in the search space. In other words alpha, beta, and delta estimate the victim position and other wolves update their positions randomly around the victim. Pseudo code of the algorithm is shown in its simplest form in Fig. 1.

\[
\text{Initialize the grey wolf population } \vec{X}_i (t = 1, 2, ..., n) \\
\text{Initialize } a, A, \text{ and } C \\
\text{Calculate the fitness of each search agent} \left( \vec{X}_a = \text{the best search agent}, \vec{X}_b = \text{the second best search agent}, \vec{X}_\gamma = \text{the third best search agent} \right) \\
\text{while } (t < \text{Max number of iterations}) \\
\text{for each search agent} \\
\quad \text{Update the position of the current search agent by equation (3.7)} \\
\text{end for} \\
\text{Update } a, A, \text{ and } C \\
\text{Calculate the fitness of all search agents} \left( \text{Update } \vec{X}_a, \vec{X}_b, \text{ and } \vec{X}_\gamma \right) \\
\text{Update } t = t+1 \\
\text{end while} \\
\text{return } \vec{X}_a
\]

Fig. 2. Pseudo code of the GWO algorithm.

5. IMPLEMENTATION

5.1. Fitness Function

In this work, we propose a new control technique based on PID. It depends on electrical resistance changes and \( K \) parameter and develops the output velocity of DC motor.

The generic equation of the proposed fitness is based on minimizing the integral of product between square time \((ISTSAE)\) and absolute value of the output velocity of the motor and can be illustrated as below (Zitzler et al., 2004):

\[ ISTAE = \int_{t_0}^{t_{max}} t^2 |\Delta w| dt \]  \hspace{1cm} (11)

We also aggravate a time domain criterion for evaluating the PID controller. A set of good control parameters to electrical resistance (from 0.1 to 0.4) and \( k \) (from 0.01 to 0.015) parameter are implemented for keep good results in
performance criteria minimization in the function. These performance criteria in the time domain comprise the overshoot, settling time, rise time and steady-state error. The final fitness function for PID controller can be illustrated as below:

$$fitness = \text{Mean}\left\{ f_{\text{int}}(Ra,K) \right\}$$ (12)

GWO is employed for optimizing the fitness function and after that a comparison between GWO and PSO algorithms is shown the high performance of the GWO.

5.2. GWO based PID Controller

In this paper, a PID controller using GWO Algorithm is utilized for achieving the optimal parameters of DC Motor speed control system.

GWO algorithm is implemented to the fitness function to control the speed of the DC motor. A set of good parameters include: $K$ and Resistance yield a good step response that will result in performance criteria minimization in the time domain. The following parameters are used to verify the performance of the PID controller parameter in GWO algorithm.

<table>
<thead>
<tr>
<th>Table 2 GWO and PSO Parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td>Parameters</td>
</tr>
<tr>
<td>Number of Search Agent</td>
</tr>
<tr>
<td>Maximum iteration</td>
</tr>
</tbody>
</table>

Table 3 lists the performance of the GWO based and PSO based PID controllers.

<table>
<thead>
<tr>
<th>Table 3 GW and PSO Parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td>Characteristic</td>
</tr>
<tr>
<td>-----------------</td>
</tr>
<tr>
<td>PSO</td>
</tr>
<tr>
<td>GWO</td>
</tr>
</tbody>
</table>

5.3. Computer Simulation Results

For achieving the performance of the proposed controller and its performance based on GWO, a definite operating point which was in time domain are examined. To show the efficacy of the proposed technique, a comparison is made with the designed PID controller with PSO algorithm. Controller Time domain efficiency is modeled by utilizing the given model in section 2. For this, operating point of table 4 based on the electrical resistance and $K$ parameter in DC motor is employed. Considered operation point is presented as follow:

<table>
<thead>
<tr>
<th>Table 4 Operation Points</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
</tr>
<tr>
<td>0.4</td>
</tr>
<tr>
<td>0.01</td>
</tr>
</tbody>
</table>

Fig. 4. GWO results and search space for the considered operating points
It is clear from the simulation results that the proposed system can have better results rather than the PSO algorithm and it can stabilize the system in the considered operation point. Although from the results, it can be concluded that GWO based controller could decrease the oscillation damping in an acceptable value, and enhanced the damping time and setting time.

Hence, GWO based controller have a good performance in both oscillation damping and time value. To achieve the proposed controller potency, ISTAE and $FD$ are utilized as below:

$$FD = (16 \times OS)^2 + (T_s)^2$$

$$ISTAE = \int_0^{t_{\text{Sim}}} |\Delta w| \, dt$$

Motor speed is considered as the maximum of setting time (TS) and overshoots (OS). Table 5 represents the numerical results for each performance indicators.

The value of the performance in GWO based PID controller is less than PSOs. Therefore, overshoot, setting time and motor speed refraction is lesson by the proposed method.

Described parameters can be evaluated as below:

$$FD = (\alpha \times OS)^2 + (T_s)^2$$

Where $\alpha$ is the weighted coefficient of the output system response. Using table 5, setting time, overshoot and FD is achieved for the operation point. System efficiency for the proposed controller has been shown in Table 5.

Table 5 Performance of GWO and PSO Controllers

<table>
<thead>
<tr>
<th>Case No</th>
<th>Over Shoot (os)</th>
<th>Setting Time ($T_s$)</th>
<th>$FD$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>PSO</td>
<td>GWO</td>
<td>PSO</td>
</tr>
<tr>
<td>1</td>
<td>0.0068</td>
<td>0.0043</td>
<td>1.1237</td>
</tr>
<tr>
<td>2</td>
<td>0.0037</td>
<td>0.0247</td>
<td>1.1174</td>
</tr>
</tbody>
</table>

6. CONCLUSION

In this paper a new optimal PID controller design is designed using the GWO algorithm. DC Motor drive speed is controlled by GWO controller. Achieved through simulation of DC motor; results showed that the designed controller can be implemented as an efficient search for the optimal PID controller. A comparison between PID-GWO and PID-PSO controllers, it shows that the proposed technique can enhance the dynamic performance of the system in a better way. The PID-GWO controller is the best which illustrated satisfactory performances and possesses good robustness toward PSOs.

REFERENCES