Adaptive Tuning of PID Controller using Crow Search Algorithm for DC motor

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Abstract: The DC motor has been commonly utilized in the industry although its maintenance is costly, more than the induction motor. Consequently, speed control of DC motor has attracted considerable researches and different algorithms have evolved. All the traditional algorithms for the Proportional Integral Derivative (PID) controller provide initial practical values for (kp, ki, and kd) PID parameters, which are manually tuned to achieving the desired performance. The manual tuning is inaccurate and a hard job, which requests comprehensive experience of the problem domain. In this paper we proposed a new method to adjustment of the PID parameters to improve tracking performance of DC motor, also provides optimal stability through creating a hybrid PID-CSA predictive model for tuning parameters of the PID controller of DC motors based on Crow search algorithm. The empirical results are compared with four type of proposed PID-CSA versions [ Integral Squared Error (ISE), Integral Absolute Error (IAE), Integral Time Absolute Error (ITAE), and Integral Time Squared Error (ITSE) ] that based on the type of error indicator functions and with other previously techniques including the Ziegler-Nichols method and PSO Optimization. The PID-CSA is more adapt in improving the steady-state error, the controller step response stability, overshoot, the rising time and settling time this give rise. The performance of the DC motor is not affected by these disturbances.

Keyword: Crow Search algorithm, DC motor, PID Tuning, Ziegler-Nichols Method, Hybrid CSA-PID Controller

1. Introduction
The DC motor speed is often adjusted to an excellent degree, which provides simple control and enhanced performance. Important industrial applications are subject to variations and disturbances in parameters. Therefore, control researchers are looking for automatic adjustment methods. PID controller can be an essential part of the control systems and it contributed 95% of the adaptive controllers systems. For perfect PID-controller control performance, proper adjustment of the PID parameters based on the knowledge of process is important [1,2]. Recently, many different control methodologies utilized in this domain such as optimal control, non-linear control, variable structure control and adaptive control that have been widely proposed for DC-motor. However, these methods are complex in theory or difficult to implement. PID control when dealing with three-stage work coverage, both for stable cases and for the temporary response provides the only best solution for many global control problems.
Despite the clear structure and strength of this method, it is very difficult to tune the gain of PID controllers [3]. To improve the abilities of conventional PID tuning parameters, multiple optimization algorithms have been suggested to improve PID tuning to provide say control and high performance such as those using (PSO) Optimization [4-8], PSO for the (MIMO) double rotor system, [9], particle filter optimization [10], genetic algorithms (GA) [11-13], artificial bees colony algorithm [14-16], the Ant-Colony algorithm [17], a new method of setting parameters based on the Mind Evolutionary Algorithm (MEA) [18], a self-organizing with genetic algorithm (SOGA) [19], Hybrid particle swarm optimization with artificial bee’s colony algorithm [20], an intelligent controller of DC Motor drive is designed using a hybrid between GA and PSA Algorithm [21]. This paper attempts to improve a PID tuning method using the Crow search algorithm (SCA). The obtained results showed the effectiveness of the recent optimization algorithms such as SCA in control engineering applications.

The rest of this paper is organized as follows. In Section 2, provide general introduction of Crow Search Algorithm. Section 3 provides a brief introduction to DC motor systems and controllers. The design of SCA-PID controller and their performance are discussed in detail in Section 4. Finally, the conclusions of the proposed system are highlighted in Section 5.

2. Crow search algorithm (SCA) algorithm

Crow considered the cleverest systems between birds. It has a big brain compared to its size and can save faces, keep in touch in difficult ways, and also hide and retrieve food by using tools in different seasons. In 2016, Askarzadeh suggested a CSA algorithm considering the attitude of crows to solve complex optimization issues. The algorithm begins the optimisation procedure in the search space by contrasting many crows in the same method of metaheuristic algorithms work. The crow's number (flock size) (N) and the crow position (i) at the time (iteration) in search limits may determine by using the equation (1), CSA tries to imitate crows intelligent attitude to find enhancement issues by using tools, keep in touch in difficult ways and hide and retrieve food during the seasons as:

\[
X^{iter}(i = 1,2,N; iter = 1, iter_{max}) \text{ where } X^{iter} = [X^{iter}_1, X^{iter}_2, ..., X^{iter}_d]
\]  

Where \(iter_{max}\) is the max iteration number. The crows can save the locations of hiding place. Perfect hiding place may save in the crow’s memory indeed. Next, crow hiding place position \(i\) at \(iter\) may represented as crow memory. So that, it can be marked as \(m_i^{iter}\). At iteration (iter), two situation may occurred when crow (\(j\)) flies to its hiding place(\(m_j^{iter}\)) & crow i need to track crow j to gain crow hiding place (\(j\)) as below : If crow (\(j\)) does not know that crow (\(i\)) is tracking it, crow (\(i\)) will discover the hiding place of crow (\(j\)) and a new position of crow (\(i\)) is gained by the below equation (2).

\[
X^{iter+1} = X^{iter} + r_i \times f^{iter} (m^{iter} - X^{iter})
\]  

where \(r_i\) is a randomly parameter between [1, 0] & (f\(^{iter}\)) is crow flight length (\(i\)) at \(iter\). If \(f\) value is bigger than 1, a global search can lead to crow following position \(i\) obtained away from \(x^{iter}\), whereas, If \(fl\) is less than (1), it may lead to a native search and gain crow following location of crow (\(i\)) between (\(x^{iter}\) & (m\(^{iter}\)), and may exceed (m\(^{iter}\)) show in [22]. Figure 1 describes the main steps of CSA algorithm. Figure 1, shown the main steps of the CSA algorithm, in which the several solutions phases used in CSA were defined and by which these steps were obtained the best solutions in the search space. The best fitness value is the last test result that has been obtained. Setting the number of flocks, probability of awareness (AP), and flight length (fl) should be performed experimentally. Note, that the higher the number of flocks, the greater the likelihood of detecting the finest or smallest global value of each iteration.
Figure 1. Flowchart of CSA for optimization process

3. Modeling of DC Motor
There are many ways to control engine speed. The goal of the speed control unit is to select a signal that represents the desired speed and drive the engine. Engine speed may or may not be measured by the speed controller. If this condition occurs, the feedback speed controller for the close loop to the speed controller will be called, and if not, it will call an open speed control loop. This speed controller is much better, but it is complicated. The DC motor is controlled by which is fed separately, and the voltage applied to the motor is the motor which changed in a special way without changing the applied voltage in the field. Figure 2 illustrates Model equivalent of DC motor.

Figure 2. The structure of a DC motor
Some useful relations are:

\[ V_a(t) = R_a i_a(t) + La \frac{di_a(t)}{dt} + V_B(t) \]  

(3)

\[ V_B(t) = K_b w(t) \]  

(4)

\[ T(t) = K_i i_a(t) \]  

(5)

\[ T(t) = T_m(t) - T_i(t) = J_m \frac{dw(t)}{dt} + B_m w(t) \]  

(6)

By substituting with equations, and take Laplace transform of equations and write in I/O form the transfer function for the DC motor can be concluded that will be used for this work [23].

\[ G(s) = \frac{w(s)}{V_a(s)} = \frac{K_t}{L_a J_m s^2 + (R_a L_m + L_a B_m) s + (R_a B_m + K_b K_f)} \]  

(7)

By substituting some parameter values for the DC developer were taken in the laboratory, as well as some fixed physical values for the DC motor, which are: the following:

\[ K_t = K_b , R = 1 \Omega , L = 0.5 H , K_i = K_b = 0.01 , K_f = 0.01 \text{ Nms} , J = 0.02 \text{ kgm}^2/\text{s}^2 \]

For the motor constants parameters value the transfer function of DC Motor is:

\[ TF = G(s) = \frac{0.01}{0.005 s^2 + 0.06 s + 1} , \quad G(s) = \frac{2}{s^2 + 12s + 20} \]  

(8)

4. Proposed PID-SCA controller

In this work, a group of good PID control parameters will produce using a hybrid methodology based on a hybrid between the PID controller and the Crow search algorithm, CSA utilized as an internal function within the PID controller of DC Motor. PID parameter selection problem is considered as a search space problem. Therefore, metaheuristic algorithms are suitable to adjust the search space to find the high correlated parameters vector; this gives rise to the disturbances that do not affect DC motor performance. As shown in Figure 3.

![Figure 3. Framework of CSA-PID Controller for DC Motor CSA-PID tuning diagram](image-url)

The framework consists of two main phases. In the initial phase, The CSA algorithm begins initiating with random parameters to approximate the global optimum, then calculates the cost value for each individual and allocates the most remarkable parameters to the PID Controller system of DC motor. Each candidate vector is setting according to the domain of the search space. The size of the vector equals the number of parameters in the PID controller. Every cell is defined by a parameter value...
within the vector. The error performance indicators are utilized to build the cost function to evaluate of obtained parameters subsets and then iteratively tune these parameters until the minimum cost function (desired response) is obtained, the performance norm is called a cost function defined by the following equations,

\[ U(t) = K_p e(t) + \frac{1}{T_i} \int e(t) dt + T_d \frac{de(t)}{dt} \]  

(9)

The \( e(t) \) variable represents the error of monitoring which is the difference between the expected input value and the actual output. This error signal is sent to the PID controller, and both the derivative and the integral of this error signal are computed by the controller. The controller's signal \( U(t) \) is now equal to the proportional gain \( (K_p) \) times the error's magnitude plus the integral gain \( (K_i) \) times the error integral plus the derivative gain \( (K_d) \) times the error derivative show equation (9) the performance index is defined as a quantitative measure in PID controller conception methods to show the system performance of the designed PID controller. This technique can often allow the designation of an 'optimum system,' and the set of system PID parameters can be modified to comply with the required specification. At the end, the empirical results are compared with four type of proposed PID-CSA versions (ISE, IAE, ITAE, and ITSE) that based on the type of error indicator functions and with other previously techniques including Z-N method and PSO algorithm.

5. Results & Discussions

A set of better PID controller parameters can provide great response which results in the time domain minimizing performance criteria. Such efficiency requirements include minimizing overshoot, rise time, setting time, and steady state error. The proposed PID controller uses a CSA algorithm to identify optimum system parameters for the DC Motor. The most important step in applying CSA algorithm in the control system is to select the cost function, which is utilized to evaluate the fitness of each Crow agent \((K_p, K_i, K_d)\). Furthermore, in this work, the proposed cost function depends on different performance indicators to explain clearly how parameters are utilized to highlight how parameters should be addressed in the selection. The system output is also represented by four indices for a CSA-PID controlled system: ISE, IAE, ITAE, and ITSE. These performance indices presented by equations 10, 11, 12 and 13 will be used as a part of the cost function as:

\[ ISE = \int_0^\infty e(t)^2 \, dt \]  

(10)

\[ IAE = \int_0^\infty |e(t)| \, dt \]  

(11)

\[ ITSE = \int_0^\infty t \, e(t)^2 \, dt \]  

(12)

\[ ITAE = \int_0^\infty t \, |e(t)| \, dt \]  

(13)

The CSA-PID optimization aim is to achieve a set of PID parameters so that the closed-loop control system has a minimum performance indices. The PID-CSA controller system is implemented using the Matlab code, which is connected to the Simulink model created. The proposed methodology implements by Intel ® Core TM i5-4700HQ, 2.4 GHz 4 GB RAM, using the Matlab framework. The global and specific parameter settings are summarised in Table 1.

| Elements                  | Value    |
|---------------------------|----------|
| Search Parameter Number   | 3        |
| Iteration number          | 80       |
| Dimension                 | 1000     |
| Search domain             | [0,10]   |

In Table 2 shows the gained PID controller parameters for both metaheuristics-based techniques such as the different versions of proposed PID-CSA controller, the PSO optimization algorithm and
traditional methods as Z-N method. As shown in Table 3, PID-CSA clearly achieved better performance in the term of step response with minimize overshoot and steady state error in controlling the speed of dc motor system.

Table 2. The values of Adjust PID parameters

| Methods       | K_p | K_i | K_d |
|---------------|-----|-----|-----|
| PID_ZN        | 98.9| 200 | 12.3|
| PID_PSO       | 249.74| 500 | 24.97|
| PID_CSA ISE   | 9.9812| 9.9969| 9.9589|
| PID_CSA IAE   | 7.8711| 10  | 1.9282|
| PID_CSA ITSE  | 20.82| 41.2084| 1.7112|
| PID_CSA ITAE  | 9.9877| 9.996| 0.037156|

Table 3. Step response values for PID controllers.

| Methods       | Overshoot | Settling Time (sec) | Rise Time (sec) | Peak value |
|---------------|-----------|---------------------|-----------------|------------|
| PID_ZN        | 18.452    | 0.415               | 0.072           | 1.18       |
| PID_PSO       | 44        | 1.2414              | 0.0777          | 1.4        |
| PID_CSA ISE   | 0.665     | 4.79                | 3.31            | 1.01       |
| PID_CSA IAE   | 0         | 4.4                 | 2.51            | 0.999      |
| PID_CSA ITSE  | 1.21      | 2.71                | 0.528           | 1.01       |
| PID_CSA ITAE  | 0         | 5.3                 | 2.52            | 0.999      |

Moreover, Figure 4 shows a sample of the track of The PID parameters with different performance index during optimization. The optimization of PID controllers tuned by the CSA algorithm method should be compared not only with their time-domain responses but also with their performance index from the four major error criterion techniques of the ITAE, IAE, ISE and ITSE performance index. The controller's robustness is defined as its ability to tolerate some amount of process parameter change without causing the feedback system to go unstable. For the proposed model the performance index comparison has similar performances, except that is optimized by ITSE where settling time, and rise time is seen to see the convergence of the optimized solution as shown in Figure 5.

Figure 4. System response using CSA-PID with a). IAE, b) ISE , c ).ITSE, d). ITAE as a Cost function.
In Figure 6, Results showed that PID-CSAITSE performed better than other controllers in the literature. It is better compared to the traditional Z-N method and PSO performance although the rise time and stability time, whereas, the PSO and Z-N method have a maximum overshoot and high oscillations for the same analysis of the DC motor transfer function.

The proposed PID-CSA system stabilizes rapidly with a lower limit exceeded. In addition, it maintains the required phase margin and gains margin to achieve the objective of improvement where the gain and phase margin and maximum gain is shown in the Table 4.

| Methods          | Phase margin (°) | Gain margin (rad/s) |
|------------------|------------------|---------------------|
| PID-CSAISE       | 91.3             | 10.7                |
| PID-CSIAE        | 103              | 1.02                |
| PID-CSAITSE      | 85.3             | 3.65                |
| PID-CSAITAE      | 102              | 1.39                |

It obtains minimum peak gain, highest phase margin, and bandwidth. We conclude therefore that the PID-CSAITSE technique is due to the better frequency response of the second ordering system, it can be argued that the proposed PID-CSAITSE can be used as an alternative method to find a better practical solution to PID controller design as depicted in Figure 7.
To prove the tracking system efficiency of the adopted PID-CSA algorithm by changing the reference speed in step change with time using repeating sequence interpolated as a system source. The attained results showed a good tracking in the control and the outstanding performance of CSA algorithm as hybrid control system gained the best response, and the least possible time as presented in Figures 8 and 9. (a, b).
Vector of output value = [100, 100, 150, 150, 50, 50].
Vector of time value = [0, 49, 50, 60, 99, 110].

(b) Figure 9. Good Tracking of CSA with IAE, ISE, ITAE, ITSE

6. Conclusions
Using the Crow Search algorithm (CSA) to optimize PID controller parameters facilitated independent adjustment of console parameters without human intervention and allowed parallel exploitation of the optimization parameter space. Simulation results proved that CSA is performing better than conventional PID and through experimental results, the proposed hybrid system provides the best set of transient responses (rise time, stability time, and minimization in settling time and eliminating at steady-state error) specifications compared to four different CSA releases based on various performance response indicators, IAE, ISE, ITSE, and ITAE, moreover, we compare with other tuning methods such as PSO-based console, and Ziegler Nichols tuning method. CSA algorithms have proven to be best at achieving transient and static response parameters.

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