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Optimal tuning proportional integral derivative controller on direct current motor using reptile search algorithm

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ABSTRACT

This paper presents the reptile search algorithm (RSA) method to optimize the proportional integral derivative (PID) parameters on direct current (DC) motors. RSA was adopted from crocodile hunting behavior. Crocodile behavior is modeled in two important steps: surrounding and attacking prey. The RSA method was applied using twenty-three classical test functions. The search method of the proposed RSA method with other existing algorithms such as particle swarm optimization (PSO), and differential evolution (DE). Integral multiplied by absolute error (ITAE) and integral of time multiplied squared error (ITSE) were used as comparisons in measuring the performance of the RSA method. The results show that the proposed method, namely RSA, has better efficiency. Optimization of PID parameters with RSA on DC motor control shows superior performance. From the experiment, the ITSE average value of the RSA method is 4.17% better than the conventional PID method.

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1. INTRODUCTION

Direct current (DC) motors are widely used in various industrial and household equipment such as servo control and other functions [1]. DC motors have effectiveness, durability, and ease in designing appropriate feedback control schemes, especially proportional-integral (PI) and proportional integral derivative (PID) types [2]. The controller is a component that functions to minimize error signals [3]. The most popular type of controller is the PID controller. The P, I, and D controller elements each aim to speed up the reaction of a system, eliminate offsets and produce large initial changes. The PID controller is proven to be able to provide good control performance even though it has a simple algorithm that is easy to understand. The crucial thing in the PID controller design is tuning P, I, and D parameters to get the desired system response.

Optimization is a process to get a lower or better value or cost from the application of a method compared to other methods [4]. Optimization has penetrated into various disciplines such as engineering, science, business and economics. Several methods have been presented to solve problems with different characteristics. Alternative methods are another way of solving problems than conventional methods [5].

This paper presents optimization of PID parameters for controlling DC motors based on reptile search algorithm (RSA). The RSA method duplicates the behavior of crocodiles in nature with the behavior of surrounding and hunting prey. The RSA method has a special step, namely updating the solution position with four new processes, namely circling by walking high or stomach, and hunting with cooperation or coordination [6]. The contribution of this paper is the use of the RSA method to control DC motors by optimizing PID parameters. This paper has a session, the second session is about RSA and DC motors. The third session is the results and discussion. The last session is the conclusion.

2. MATERIALS AND METHOD

2.1. Reptile search algorithm

The RSA method provides a modeling of the exploration and exploitation phases by duplicating the circling, hunting, and social behavior of crocodiles in nature. In RSA, the optimization process starts with a set of candidate solutions (X), which is generated stochastically, and the best solution obtained is considered to be close to the optimum in each iteration [6].

$$X = \begin{bmatrix} X_{1,1} & \cdots & \cdots & X_{1,n} \\ X_{2,1} & \cdots & \cdots & X_{2,n} \\ \vdots & \vdots & \vdots & \vdots \\ X_{N,1} & X_{N,j} & \cdots & X_{N,n} \end{bmatrix} \quad (1)$$

$$x_{ij} = rand \times \left(UB_j - LB_j\right) + LB_j \quad i = 1,2 \ldots, m\,; j = 1,2, \ldots \ldots n \quad (2)$$

The set of candidate solutions that are randomly generated are X, j indicating the position of the *i th* solution. The number of candidate solutions is N. N is the dimension measure of the given solution. *rand* is a random value. The lower and upper bounds of the given problem are LB_j and UB_j.

Exploration: RSA in the exploration phase has a model that imitates the behavior of crocodiles surrounding prey, namely walking high and belly walking. The crocodile's movement in the exploration phase cannot approach the prey because the crocodile's movement will be easily recognized. The exploration phase is carried out optimally because it relates to the next stage. RSA is characterized by the ability to switch between exploration and exploitation. This shift is based on four conditions. The RSA exploration mechanism is to explore the search area and approach to find a better solution based on two strategies, namely the high walk strategy ($t \leq \frac{T}{4}$) and the belly walk strategy ($t \leq 2\frac{T}{4}$ and $t > \frac{T}{4}$).

$$X_1(t+1) = \begin{cases} Best_j(t) \times P_{i,j}(t) \times \beta - S_{i,j}(t) \times rand & t \leq \frac{T}{4} \\ Best_j(t) \times x_{r1,j}(t) \times ES(t) \times rand & t \leq 2\frac{T}{4} \ and \ t > \frac{T}{4} \end{cases} \quad (3)$$

$$P_{i,j}(t) = Best_j(t) \times Y_{i,j}(t) \quad (4)$$

$$S_{i,j}(t) = \frac{Best_j(t) \times x_{r2,j}(t)}{Best_j(t) + e} \quad (5)$$

$$ES(t) = 2 \times r_3 \times (1 - \frac{1}{T}) \quad (6)$$

$$Y_{i,j}(t) = \propto + \frac{x_{i,j}(t) - M(x_i)}{Best_j(t) \times \left(UB_j - LB_j\right) + \epsilon} \quad (7)$$

$$M(x_i) = \frac{1}{N} \sum_{j=1}^{n} x_{(i,j)} \quad (8)$$

where the *j-th* position in the best solution obtained is $Best_j(t)$. Random number between 0 and 1 is *rand*. the current number of iterations is denoted by t. The maximum number of iterations is T. β is a sensitive parameter used as a control for exploration accuracy (ie, run height) during iterations and has a value of 0.1. $P_{(i,j)}(t)$ is the hunting operator for the *j th* position. Reduce function $(S_{(i,j)}(t))$ is the value applied to reduce the search area. Evolutionary sense $(ES(t))$ is the ratio of the probability of having a gradient value randomly between 2 and -2 across the number of iterations. $r2$, is a random value that has a value of [1 N]. r_3 a is a random value between 1 and -1. $Y_{(i,j)}(t)$ is the percentage difference between the positions of the best solution obtained. The mean position of the solution is $M(x_i)$. N is the number of candidate solutions.

Exploration: Crocodiles have two mechanisms in hunting, namely hunting coordination ($t \leq 3\frac{T}{4}$ and $t > 2\frac{T}{4}$) and cooperation ($t \leq T$ and $t > 3\frac{T}{4}$). This mechanism makes it easier for crocodiles to approach prey. This mechanism is included in the exploitation phase which has an optimal solution.

$$X_1(t+1) = \begin{cases} Best_j(t) \times P_{i,j}(t) \times rand & t \leq 3\frac{T}{4} \text{ and } t > 2\frac{T}{4} \\ Best_j(t) - P_{i,j}(t) \times \in - S_{i,j}(t) \times rand & t \leq T \text{ and } t > 3\frac{T}{4} \end{cases} \tag{9}$$

2.2. DC motor

DC motors can be found in a variety of industrial and household applications. This DC motor has a cheaper price and easier maintenance costs. Conventional DC motor control uses PI and PID. Advances in methods and algorithms are increasing every year [7]. Several new control methods based on computation are gaining popularity [8]. DC motor is a tool that is widely used for various metaheuristic applications [9]. DC motors have easy-to-observe characteristics making it easier to evaluate and measure performance. Several studies have focused on the output of a DC motor, namely the speed.

A very important aspect in the design of the PID controller is the determination of the parameters of the PID controller so that the close loop system meets the desired performance criteria. This is also known as controller tuning. Several conventional methods of PID control have been presented in several papers such as Ziegler-Nichols [10], and Cohen-Coon [11]. The conventional method has the characteristic that it requires more time in optimizing PID parameters and sometimes produces excessive overshoot values. Alternative methods have been presented to overcome the weakness in PID tuning. One of the most popular is the metaheuristic method. Several papers have presented the application of several variants of metaheuristic methods such as atom search optimization algorithm [12], Henry gas solubility optimization [13], whale optimization algorithm [14], [15], manta ray foraging optimization [16], [17], bee colony algorithm [18]–[20], African buffalo optimization [21], and crow search algorithm [22], [23]. The block diagram of a DC motor with a PID controller can be seen in Figure 1.

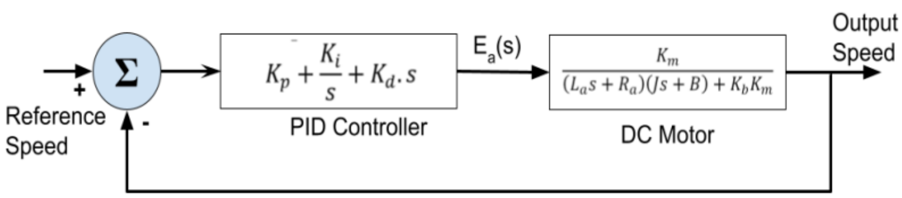

Figure 1. Schematic of DC motor with PID [24], [25]

2.3. The proposed RSA to controlling DC motor

Integral of time multiplied by absolute error (ITAE) was chosen to measure the performance of the speed control. The ITAE equation is [26], [27]:

$$ITAE = \int_0^{\infty} t.e(t).dt \tag{10}$$

The method is applied to obtain the PID parameter which is used as a DC motor controller. The schematic of the RSA attached to the PID controller on a DC motor can be seen in Figure 2 (see in appendix).

3. RESULTS AND DISCUSSION

The parameters of the DC motor can be determined based on the data sheet of the device or by carrying out various experiments in the laboratory. In the experiment, the laptop used was an Intel i5 processor (2.2 Ghz) and 8 GB of ram. Programming code and simulation of the RSA method using the MATLAB/Simulink application. Table 1 is the detail of the RSA parameters. To determine the performance, RSA was compared with the particle swarm optimization (PSO), and differential evolution (DE) methods. Figure 3 is the convergence curve. Parameters of the PID control that have been obtained from the method used. It can be seen in Table 2.

Table 1. RSA parameter

Parameter	Value
Number of search solution	20
T	10
$\propto, \beta$	0.1; 0.005
[UB; LB]	[10; 0]

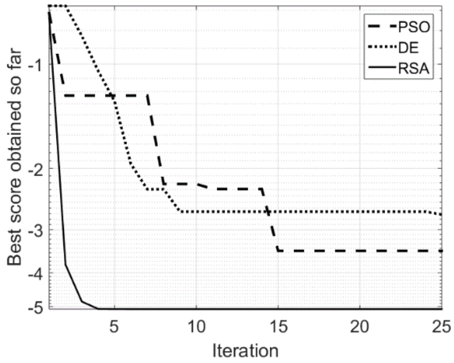

Figure 3. The convergence curve

Table 2. The result PID value

Method	P	I	D
PID	4.5607	1.105	0.9201
PSO	2.3549	2.3549	1.4887
DE	4.5328	4.5328	4.5328
RSA	4.6737	1.2415	0.9544

To determine the performance of the RSA-PID method, the experiment used three problems. Case 1 is in accordance with the specifications shown in Figure 2. Comparative analysis of the proposed RSA-PID approach with PID, PSO-PID, and DE-PID is shown in Table 3. Comparison of step speed responses for different controllers is shown in Figure 4 with case 1. The RSA-PID method has no overshoot value and has the best ITSE value. The worst ITSE value is the PSO-PID method. Meanwhile the method that has the worst overshoot is DE-PID.

Table 3. Comparison result in case 1

Controller	Overshoot	Rise Time	Settling Time	ITSE
PID	1.0129	0.0223	0.0354	0.0036
PSO-PID	1.0024	0.2	0.3313	0.0669
DE-PID	1.2205	0.0024	0.3	0.0262
RSA-PID	No Overshoot	0.0229	0.0539	0.0035

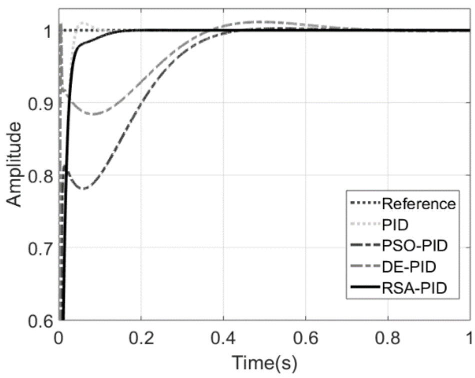

Figure 4. Step response in case 1

Case 2 is changing the values of R_a=0.2 and K=0.008. Comparative analysis of the RSA-PID method with other methods can be seen in detail in Table 4. Figure 5 is the step response of the various methods used in case 2. In case 2, the overshoot and ITSE values of the RSA-PID method are 1.0118 and 0.0024. The overshoot and ITSE values of the RSA-PID method are the best. On the other hand, the PSO-PID method has the worst overshoot and ITSE values.

In case 3, the DC motor paramater is changed to the values of Ra=0.6 and K=0.008. Details of the comparative analysis with case 3 can be seen in Table 5. The graph of the comparative analysis in case 3 is shown in Figure 6. In case 3, the ITSE value and the worst overshoot are the PSO-PID method.

Table 4. Comparison result in case 2

Controller	Overshoot	Rise Time	Settling Time	ITSE
PID	1.0106	0.0163	0.0362	0.0025
PSO-PID	1.0541	0.0325	0.3365	0.0119
DE-PID	1.023	0.0026	0.295	0.0031
RSA-PID	1.0118	0.0158	0.0353	0.0024

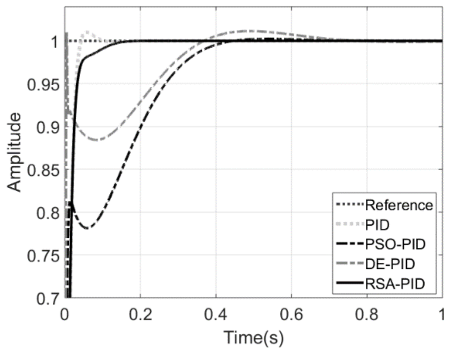

Figure 5. Step response in case 2

Table 5. Comparison result in case 3

Controller	Overshoot	Rise time	Settling time	ITSE
PID	1.2	0.017	0.0448	0.0018
PSO-PID	1.0448	0.0376	0.337	0.0099
DE-PID	1.0196	0.0026	0.09	0.0027
RSA-PID	1.002	0.0165	0.0435	0.0017

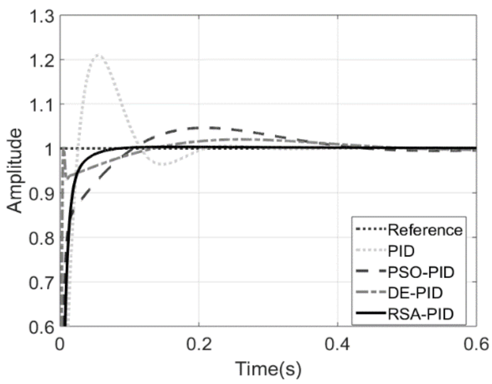

Figure 6. Step response in case 3

4. CONCLUSION

PID optimization of DC motors is a popular and attractive field in power systems. This relates to the whole process carried out by a DC motor. This paper presents the RSA-PID method to optimize PID parameters on DC motors. This paper uses 3 cases to test the capability of the RSA-PID method. In addition, comparison methods are also used, namely PID, PSO-PID and DE-PID. From the case 1, it was found that the ITSE value of the RSA-PID method could decrease by 2.78% from the PID method. RSA-PID method has no overshoot value. In case 2, the RSA-PID method has an ITSE value of 4.17% better than the conventional PID method. In the last experiment, the ITSE value of the RSA-PID method was 5.57% better than the conventional PID method.

APPENDIX

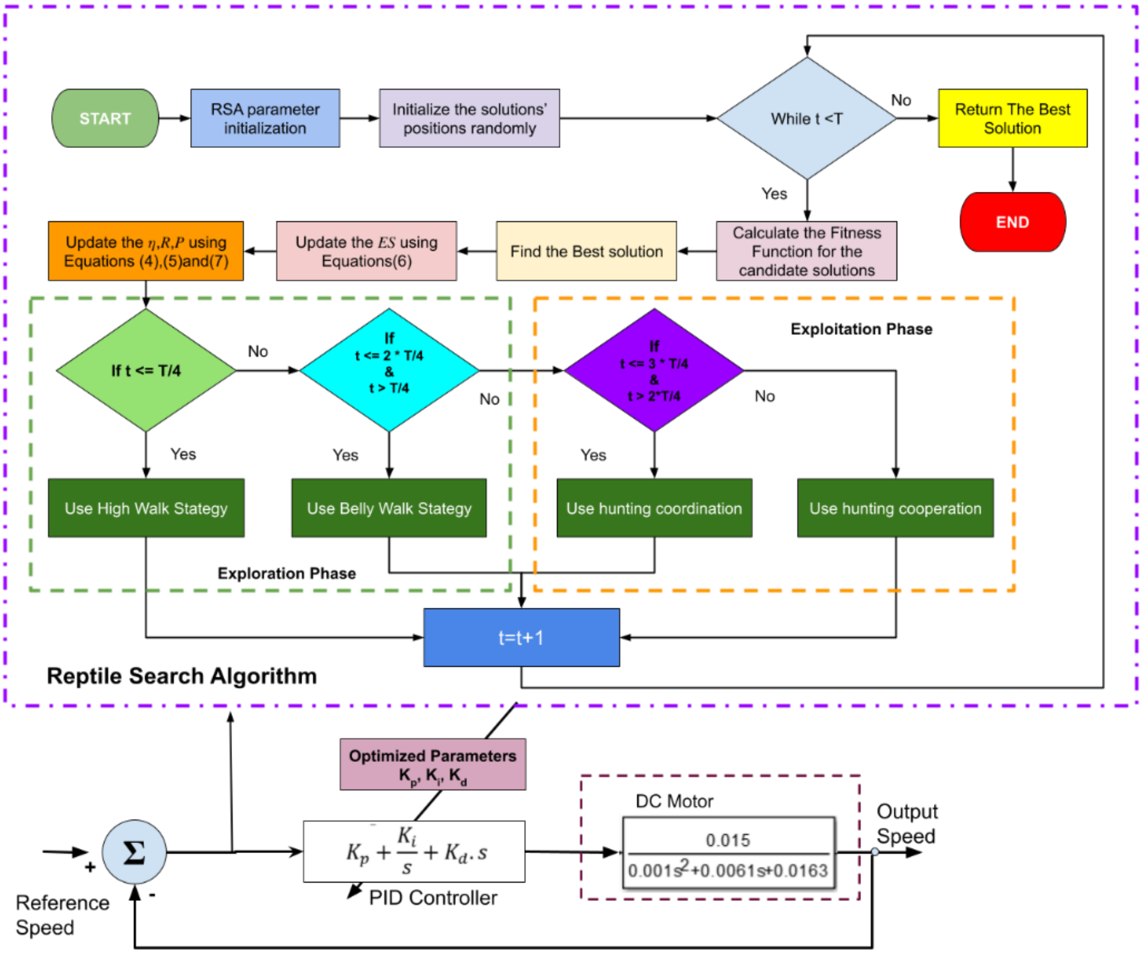

Figure 2. Optimization of PID controller parameters using RSA

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