Sand cat swarm optimization for controlling PID in DC motor

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ABSTRACT

In this article, the direct current (DC) motor control approach is presented using the sand cat swarm optimization (SCSO) method to obtain the best proportional integral derivative (PID) parameters. DC motors are popular equipment. In addition, DC motors are easy to apply. SCSO is a method that adopts the desert cat's life in nature when searching for prey. This cat is able to detect low frequencies below 2 kHz and also has an extraordinary ability to dig for prey. This research was carried out using the MATLAB/Simulink application. To obtain the performance of the SCSO method, a comparison method was used, namely particle swarm optimization (PSO), gray wolf optimizer (GWO), whale optimization algorithm (WOA), and aquila optimizer (AO). From the results of the study, it was found that the settling time value and integral total weighted absolute value error (ITAE) value of the SCSO method were the best compared to other methods.

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1. INTRODUCTION

High performance motor propulsion in industrial and other purpose applications such as household appliances and robotics is essential [1], [2]. Motor drives that have high performance must be able to receive dynamic commands and load control responses. Electric drives are key in most industrial manufacturing and commercial applications [3], [4]. Direct current (DC) motors are easy-to-apply and widely accepted drives. The advantages of being easy to implement and reliable making it a favorite driver in most industrial and commercial applications [5]–[7]. DC motor is a power conversion that converts electrical energy into mechanical energy. Speed control is an intentional variation of speed that is performed both automatically and manually. The DC motor can be accelerated and decelerated so it provides excellent speed control. The comparison of the torque characteristics of the AC motor speed is lower than that of the DC motor. DC motors have a long time use range for adjustable speed control.

Characteristics of DC motor that can be maintained to a certain extent so that it is easily controlled and high-performance. Some DC motor controls have been presented, both conventional or computing. Proportional-integral-derivative (PID) controlling has been applied in several years in the industry and other applications as a control process. Weaknesses of PID Controller are unwanted speed overshoot values sometimes appear and are slow to respond when there is a change in load. In addition, it has a sensitivity to the controller to get KI and KP. PID performance depends on the accuracy of the model and system parameters. Therefore, there are controlling needs that can overcome losses from PID control. Some researchers have begun to present several combinations of PID with other methods as a method of optimizing

PID parameters such as particle swarm optimization (PSO) [8]–[12], grey wolf optimizer (GWO) [13]–[15], whale optimization algorithm (WOA) [16]–[18], simulated annealing (SA) [19]–[21], genetic algorithm [22]–[25], and aquila optimizer (AO) [26]. DC motor control research using metaheuristic methods has been widely presented by several researchers such as the application of the sine cosine algorithm (SCA) [27], Harris Hawks optimization algorithm (HHO) [28], and arithmetic optimization algorithm (AOA).

Although there are many studies that present PID optimization in DC motors. The PID optimization area still has a lot of room to be explored, especially the use of the latest optimization methods. In this study, the latest optimization method is presented, namely sand cat swarm optimization (SCSO) which is applied to estimate PID parameters as DC motor control. SCSO method is a method that adopts the behavior of a sand cat trying to survive in nature. This cat is capable of detecting low frequencies below 2 kHz and also has an amazing ability to dig for prey. In addition to its efforts to identify more potential local regions in the global field, SCSO is expected to exhibit balanced behaviour between phases and perform well in high-dimensional and multi-objective issues. It can also be used to other technical challenges, such as composite problems [29]. The contributions of this research are:

- Application of SCSO method to estimate PID parameter value as DC motor control.
- The achievement of the offered method is tested by comparing it with the PSO, GWO, WOA.

The structure of this paper is the second part regarding SCSO method and DC motor. The third part is the results and discussion. The last part is to draw conclusions.

2. METHOD

2.1. Sand cat swarm optimization

2.1.1. Searching the prey (exploration)

The SCSO algorithm is duplicated from the behavior of the sand cat in nature which has the main behavior of looking for prey and attacking its prey. Sand cats have the ability to detect low-frequency noises. So they can find prey in the ground. With this ability, the sand cat can quickly find prey. The sand cat's search for prey relies on low-frequency noise. SCSO depends on the ability of hearing in low frequency detection. The prey search process in the SCSO method can be modeled mathematically as (1)-(4):

$$\vec{r}_G = S_M - \left(\frac{2\times S_M \times iter_c}{Iter_{Max}}\right) \tag{1}$$

$$R = 2 \times \vec{r}_G \times rand - \vec{r}_G \tag{2}$$

$$\vec{r} = \vec{r}_G \times rand \tag{3}$$

$$\overrightarrow{Pos}(t+1) = \vec{r} \cdot \overrightarrow{Pos_{bc}}(t) - rand \cdot \overrightarrow{Pos_c}(t) \tag{4}$$

Where $\vec{r}_G$ indicates a general sensitivity range that decreases linearly from 2 to 0 following iterations according to the working mechanism of the proposed algorithm to approach the hunt sought and not lose or miss it. S_M is a duplication of the sand cat's auditory characteristics, the value is assumed to be 2. $rand$ is a random value between 0 and 1. R is the vector used to maintain the phase transition of the exploration and exploitation phases. This can be modeled on (2) each sand cat (search agency) updates its own position based on the position of the best candidate ($\overrightarrow{Pos_{bc}}$), current position ($\overrightarrow{Pos_c}$) and his sensitivity range ($\vec{r}$). Each sand cat has a different sensitivity range. This is to avoid the trap of local optimum and is modeled mathematically with (3). The sand cat can find other best possible prey positions (4). In (4) provides another opportunity for the algorithm to find a new local optimum in the search area.

2.1.2. Invading on the prey (exploitation)

Sand cats hunt prey by relying on the performance of their ears. The exploitation phase of SCSO can be modeled by (5):

$$\overrightarrow{Pos_{rnd}} = \left|rand \cdot \overrightarrow{Pos_b}(t) - \overrightarrow{Pos_c}(t)\right|, \overrightarrow{Pos}(t+1) = \overrightarrow{Pos_b}(t) - \vec{r} \cdot \overrightarrow{Pos_{rnd}}(t) \cdot \cos\theta. \tag{5}$$

Where (θ) is a random angle of the direction of motion. Random angles have values between 0 and 360 so their values are in the range -1 and 1. With this method, the members of the population move in a circle against the search space. The roulette wheel selection algorithm is used by SCSO to select a random corner for each sand cat. This aims to update the hunting position to approach the prey. In addition, random angles are used to avoid local optimum traps. Pos_{rnd} shows the random position and assures that the cats implicated can be near to prey.

2.1.3. Exploration and exploitation

Parameters r_G and R maintain the balance of the exploration and exploitation phases. Applying this parameter provides a smooth two-phase switching. The rg parameter has implications for the R parameter. The r_G value drops from 2 to 0 during iteration. On the other hand, the value of R is a random value in the interval $[-2rg, 2rg]$. When R is below or equal to 1, search agents are forced to exploit. On the other hand, search agents are forced to explore and find prey. In exploration, cats can avoid being trapped by local optimals with different radius values. This parameter is also effective in the exploitation phase. The mathematical modeling of this phase can be written in (6).

$$\vec{X}(t+1) = \begin{cases} \left(\overrightarrow{Pos_b}(t) - \overrightarrow{Pos_{rnd}}(t)\right) \; |R| \leq 1; Exploitation \\ \vec{r} \cdot \left(\overrightarrow{Pos_{bc}}(t) - rand \cdot \overrightarrow{Pos_c}(t)\right) \; |R| > 1; Exploration \end{cases} \quad (6)$$

2.2. DC motor

The DC motor has the characteristics of one control system that can work in two control modes. The first mode is armature control mode where the field current is constant. On the other hand, is called a field control mode with a fixed armature current [30]. The faetures of DC motor compossed of resistance, inductance and back electromotive-force voltage as shown in Figure 1. The dc motor parameters used in this research can be seen in Table 1.

$$V_a(s) = (R_a + L_a.s).I_a(s) + e_b(s) \quad (7)$$

$$e_b(s) = K_b\omega(s) \quad (8)$$

Where R_a and L_a are armature resistance and armature inductance. e_b is back electromotive force.

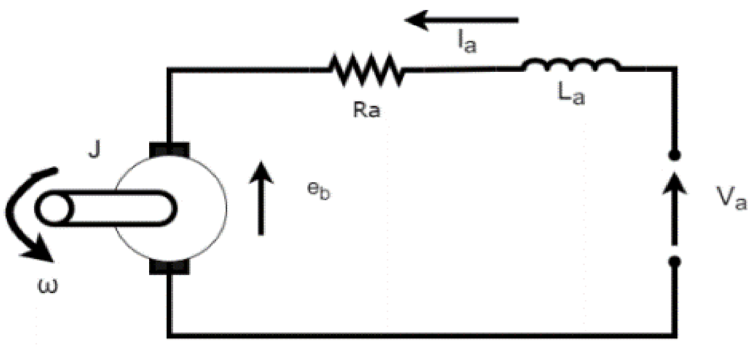


Figure 1. Illustration DC motor circuit

Table 1. DC motor parameters

Parameter	Value
Back emf constant (K_b)	0.01 Ω
Armature resistance (R)	2 H
Armature inductance (L)	0.25 kg.m^2
Mechanical inertia (J)	0.02 N·m·s⁄rad
Friction coefficient (B)	0.05 V·s⁄rad
Motor torque constant (M)	0.015 N·m⁄A

2.3. The proposed SCSO for setting DC motor

Adaptive control settings are used to obtain the optimal value of the transient condition. This study uses the SCSO method to obtain PID parameters consisting of $Kpub_j$, Ki, and Kd. Illustration of the proposed method can be seen in Figure 2.

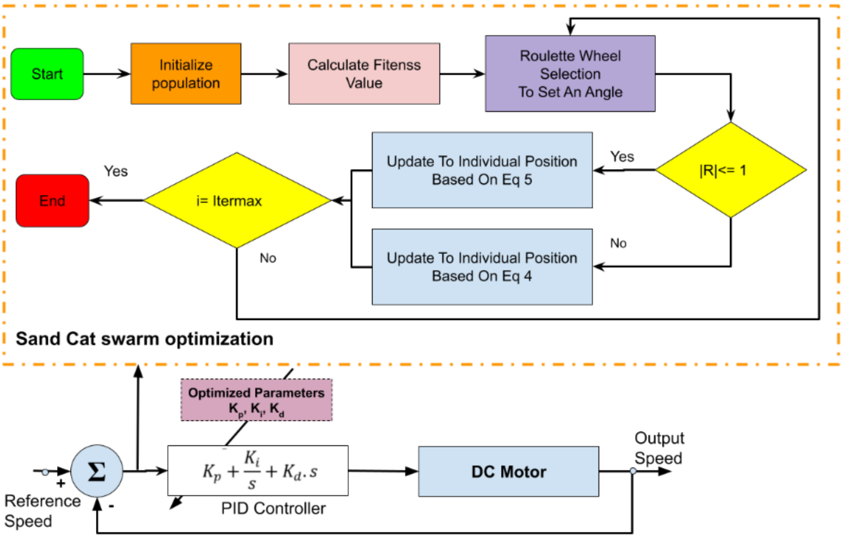


Figure 2. Proposed method diagram

3. RESULTS AND DISCUSSION

SCSO algorithm code is done and simulated using a laptop using an amd A9-9425 (3.1 Ghz) laptop and 4 GB of RAM. The application used is MATLAB/Simulink. Details of the SCSO parameters can be seen in Table 2. Performance measurement of the proposed method SCSO-PID uses the global optima function and uses the PSO, GWO, WOA, and AO methods as comparisons. The results of this comparison can be seen in Figure 3 (in Appendix) and Table 3.

Table 2. The parameters of SCSO

Variable	Speed (rpm)
S_M	2
$Iter_{Max}$	10
Search agent	50
θ	0-360

Tabel 3 The result PID value

Method	P	I	D
PID	3.44	9.9239	0.51
PSO	2.3549	2.3549	1.4887
GWO	3.6111	9.8885	0.5693
WOA	3.7422	10.0000	0.5216
AO	3.18025	10	0
SCSO	3.6182	10	0.5611

In Figures 3(g) F7, 3(n) F14, 3(o) F15, 3(p) F16, 3(q) F17, 3(r) F18, 3(s) F19, and 3(t) F20 (in Appendix), the SCSO functions F7, F14, F15, F16, F17, F18, F19, and F20 have the lowest convergence curves. However, when it comes to F1, F2, F3, F4, F5, F6, F8, F9, F10, F11, F12, and F13, the AO algorithm has the lowest convergence value. It can be seen in Figures 3(a) F1, 3(b) F2, 3(c) F3, 3(d) F4, 3(e) F5, 3(f) F6, 3(h) F8, 3(i) F9, 3(j) F10, 3(k) F11, 3(l) F12, and 3(m) F13 (in Appendix). The performance measurement of the SCSO-PID method uses the integral total time-weighted square of error (ITSE) and the integral total weighted absolute value error (ITAE). The ITSE and ITAE equations are as (9) and (10):

$$ITAE = \int_0^{\infty} t.e(t).dt \tag{9}$$

$$ITSE = \int_0^{\infty} t.e^2(t).dt \tag{10}$$

The outputs of the DC motor speed reaction by a speed reference of 1 PU for the PID, PSO-PID, GWO-PID, WOA-PID, AO-PID, and SCSO-PID controllers are displayed in Figure 4. Analyses of transient responses of the PID, PSO-PID, GWO-PID, WOA-PID, AO-PID, and SCSO-PID can be seen in Table 3. From the comparison of ITAE values presented in Table 4, the ITAE value of the SCSO-PID method shows the lowest value of the other methods, which is 0.0107. On the other hand, the highest score of ITAE is owned by the PSO method of 0.0304. Meanwhile, the ITSE value of the SCSO-PID method shows the same value as the GWO-PID and WOA-PID methods, which is 0.0031. The lowest score for ITSE belongs to the AO-PID method and the highest value is owned by the PSO-PID method. The overshoot value of the SCSO-PID method is 1.0006. Meanwhile, the comparison method that does not have an overshoot value is the GWO-PID method. Meanwhile, the comparison method that does not have an overshoot value is the GWO-PID method. SCSO-PID method has the best settling time response, which takes 0.772 seconds to respond.

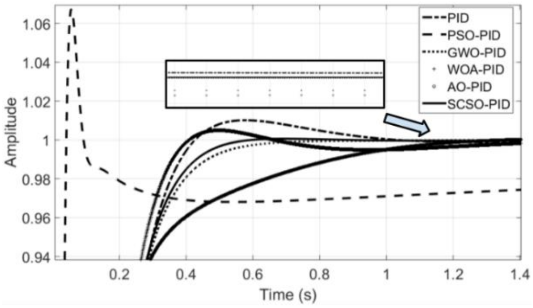


Figure 4. Step response with a speed reference of 1 PU

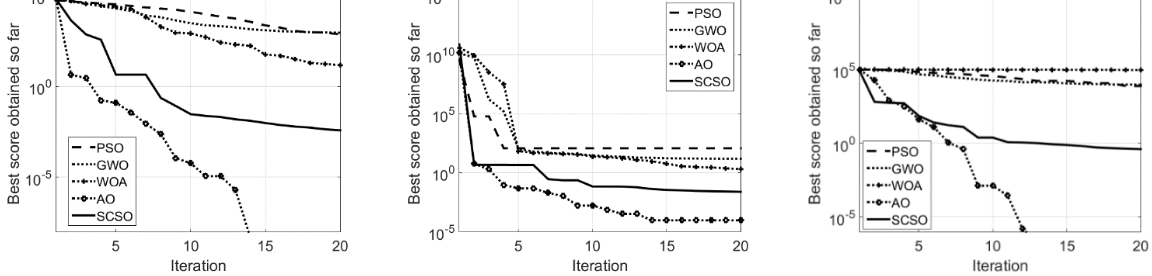
Table 4. Comparison results with reference speed 1

Controller	Overshoot	Rise time	Settling time	ITSE	ITAE
PID	0.0066	0.422	2.226	0.34	0.0134
PSO-PID	0.0674	0.026	5.609	0.41	0.3404
GWO-PID	No overshoot	0.418	1.601	0.31	0.0111
WOA-PID	0.0049	0.407	2.016	0.31	0.0128
AO-PID	0.0007	0.402	1.672	0.25	0.0174
SCSO-PID	0.0006	0.416	0.772	0.31	0.0107

4. CONCLUSION

DC motor control is one of the most popular areas because DC motors are one of the most widely applied and easy to implement control equipment. In this article, DC motor control is presented using the SCSO method. From the experimental results with optimal function, the SCSO method has a better convergence value than the PSO, GWO, and WOA methods. Meanwhile, the application of the SCSO method as a DC motor control provides the best value for settling time response. The value of settling time from the SCSO method is 96.28% better than the PID method. Meanwhile, the SCSO method is able to reduce the overshoot value by 0.6% from the PID method. The ITAE value of the SCSO-PID method has a better value of 20.15% compared to the PID method.

APPENDIX



(a) (b) (c)

Figure 3. The convergence curve of benchmark function; (a) F1, (b) F2, and (c) F3

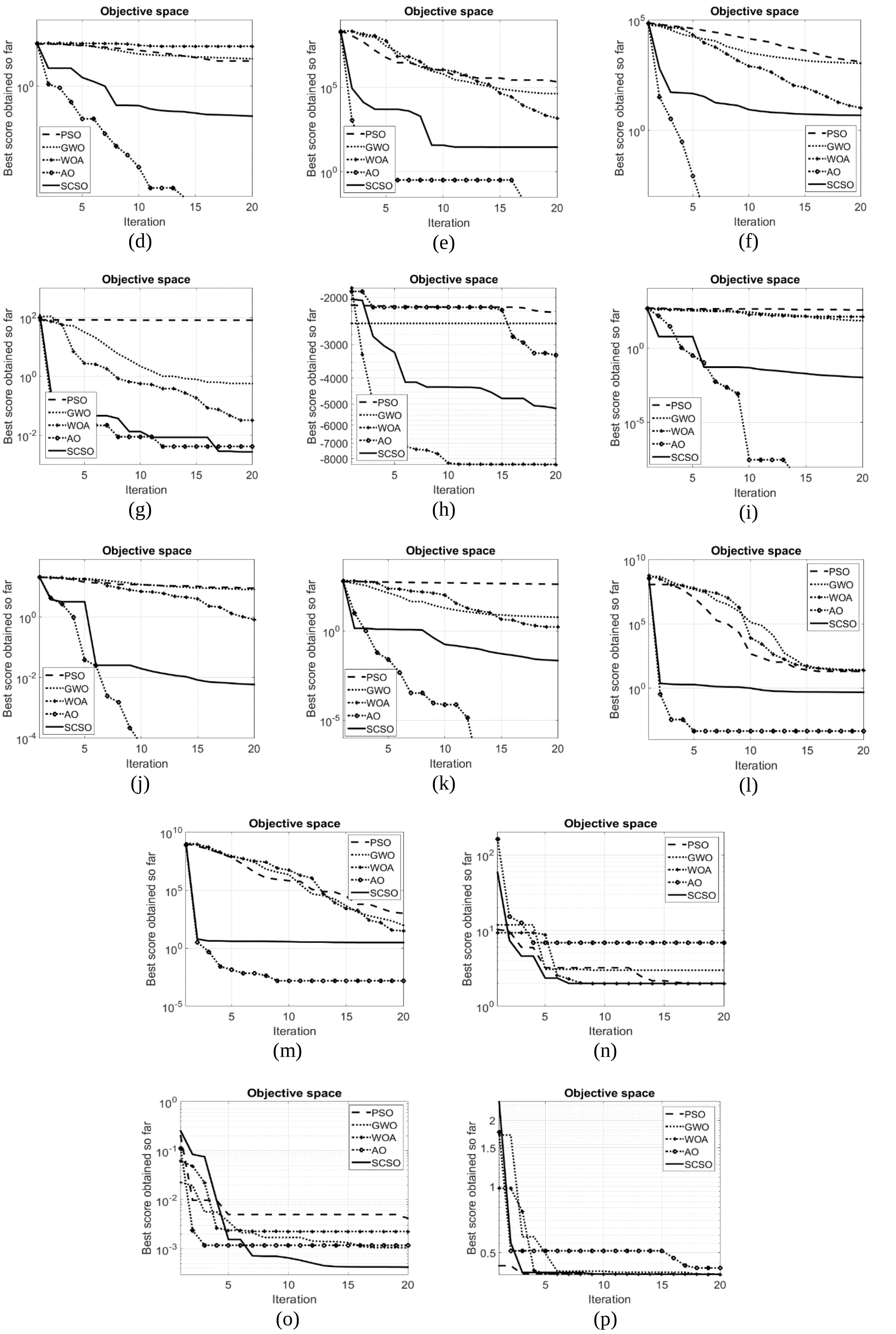
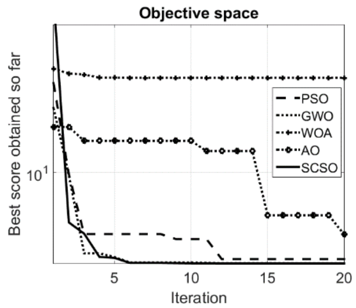
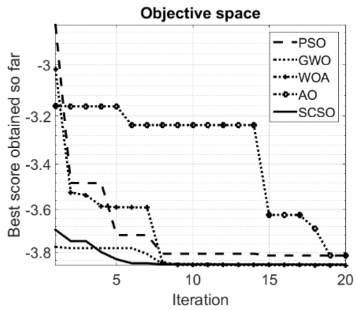


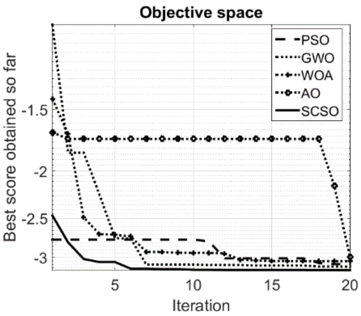
Figure 3. The convergence curve of benchmark function; (d) F4, (e) F5, (f) F6, (g) F7, (h) F8, (i) F9, (j) F10, (k) F11, (l) F12, (m), F13, (n) F14, (o) F15, and (p) F16 (*continue*)



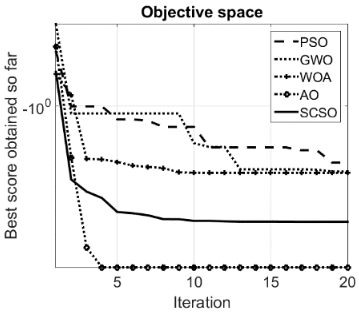
(q)



(r)



(s)



(t)

Figure 3. The convergence curve of benchmark function; (q) F17, (r) F18, (s) F19, and (t) F20 (*continue*)

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