Advances in Sine Cosine Algorithm: A comprehensive survey

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Advances in Sine Cosine Algorithm: A comprehensive survey

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Abstract
The Sine Cosine Algorithm (SCA) is a population-based optimization algorithm introduced by Mirjalili in 2016, motivated by the trigonometric sine and cosine functions. After providing an overview of the SCA algorithm, we survey a number of SCA variants and applications that have appeared in the literature. We then present the results of a series of computational experiments to validate the performance of the SCA against similar algorithms.

Keywords Sine Cosine Algorithm · Meta-heuristic optimization algorithms · Optimization problems · Population-based algorithms

1 Introduction

Optimization methods, especially meta-heuristics, are classified into two essential parts: local search methods and population search methods (Abualigah et al. 2020c). Local search methods run with just one solution during their optimization process and they attempt to develop their solution using a neighborhood mechanism (Bolaji et al. 2016), such as tabu searches (Glover 1977), simulated annealing (Kirkpatrick et al. 1983), hill climbing (Koziel and Yang 2011), or β-hill-climbing (Abualigah et al. 2017). Nevertheless, the main advantage of these methods is their exploitation search-ability, while the main disadvantage is their focus on exploitation (local) search methods rather than on exploration (global) searches. Counter to population search methods, which are run by using multi-solutions (populations) at each run, candidate solutions are improved because they generate one or more better solutions at each iteration. These methods are powerful in recognizing and encouraging areas in a wider search space but they are still inefficient in exploiting the widest regions of the search space (Shehab et al. 2017) as results, and the probability of their getting trapped in local optima is high.

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Evolutionary computation and swarm intelligence are other classes of population search methods (Abdelmadjid et al. 2013). These methods are based on the real and natural biological growth of social connections and the operation of natural animals and others in life. Examples of swarm algorithms include Salp Swarm algorithm (SSA) (Mirjalili et al. 2017), Moth-Flame Optimization (MFO) algorithm (Mirjalili 2015b), Grey Wolf Optimizer (GWO) algorithm (Mirjalili et al. 2014), Differential Evolution (DE) algorithm (Storn and Price 1997), Genetic algorithm (GA) (Deb et al. 2002), Particle Swarm Optimization (PSO) algorithm (Kennedy 2011), Gravitational Search algorithm (GSA) (Rashedi et al. 2009), Bat Algorithm (BA) (Yang 2010b), Artificial Bee Colony (ABC) algorithm (Karaboga and Basturk 2007), Krill Herd (KH) algorithm (Abualigah 2019a), and Ant Lion Optimizer (ALO) algorithm (Mirjalili 2015a).

Sine Cosine Algorithm (SCA) is a population-based optimization algorithm introduced by Mirjalili in 2016 for solving several optimization problems. The SCA generates various initial random solutions and asks them to shift towards the best solution using a mathematical model based on sine and cosine functions. Various random and adaptive variables also are combined with this algorithm to maintain exploration and exploitation of the search space in various milestones of optimization (more details of the ALO algorithm are provided in Mirjalili 2016). The main two techniques are provided in SCA (population search strategy and local search strategy) to produce an intelligent algorithm suitable to search effectively by the two main search strategies (global exploration and local exploitation). Related to similar meta-heuristic algorithms, SCA is easy, flexible, and simply implemented; as such, it can be applied to solve various kinds of optimization problems. Due to these features, SCA is successfully applied to solve different optimization problems, such as scheduling (Abdelsalam and Mansour 2019), feature selection (Belazzoug et al. 2020), inverse problem and parameter estimation (Aydin et al. 2019), networking (Raut and Mishra 2019), classification (Majhi 2018), economic power dispatch planning (Gonidakis and Vlachos 2019), benchmark functions (Tuncer 2020), power energy (Suid et al. 2019), proportional integral derivative controller (Nayak et al. 2019), and image processing (Elfattah et al. 2016).

In this paper, all SCA-based users are provided with a comprehensive survey over the last few years since 2016. We focused on the general procedures of SCA, its variants, its applications, and its results compared with other similar algorithms. Finally, this review paper gives the advantages and disadvantages of SCA and recommends potential future work directions for the researchers who are interested. Based on this review paper, researchers will be able to fully understand the design and the running procedures of SCA, as well as to recognize the different improvement spaces and different fields that utilize SCA to determine optimal solutions. The authors will consider this work when required to solve any optimization problem or to look in the literature for meta-heuristic optimization algorithms. We used Google Scholar to collect the Data since it is one of the dominant scientific search engines; furthermore, many similar published papers, e.g. Abualigah (2020), Abualigah et al. (2020a, b) used Google Scholar for collecting the data as well. The data is fully collected by searching using three words in the title of the papers: “Sine”, “Cosine”, and “Algorithm”.

The remainder of this paper is arranged as follows: Sect. 2 introduces the SCA by highlighting its components and procedures. Section 3 presents variants of the SCA and its improvements. Application disciplines and its progress are discussed in Section 4. Section 5 presents the results of SCA and compares it with other similar algorithms. Section 6 discusses theoretical aspects, assessment, and evaluation of SCA. Finally, Sect. 7 outlines some concluding remarks and several potential directions for future work.

2 Sine Cosine Algorithm (SCA)

Generally, population search methods begin the optimization process by a set of randomly initial solutions (population). These random solutions are evaluated iteratively by the used objective function and developed by a set of optimization operators that are the basis of the used optimization technique (Tong and Pearson 2008; Pal et al. 2019). Since population search techniques seek to find the optima of problems stochastically, there is no guarantee of obtaining a solution quickly in a single run (Mirjalili et al. 2020). But with several numbers of stochastic solutions and optimization processes (iterations), the likelihood of winning the global optimum increases (Mirjalili 2016).

Despite the differences between optimization algorithms in the domain of stochastic population-based techniques, the most well-known of the optimization processes are divided into two main phases: exploration (diversification, which acts as a global search) versus exploitation (intensification, which acts as a local search) (Črepinšek et al. 2013; Banerjee and Nabi 2017). In the exploration phase, the optimization algorithms merge the random solutions in the collection of solutions abruptly with a high degree of randomness to get the promising areas of the available search space. In the exploitation phase, there is slower progress (gradual) in the random solutions, and random changes are considerably less than those in another phase (exploration) (Chen et al. 2020; Mirjalili 2016).

In SCA, the mathematical equations for updating positions are given below. For both phases, see Eqs. (1) and (2):

$$X_i^{t+1} = X_i^t + r_1 \times sin(r_2) \times \left| r_3 P_i^t - X_i^t \right| \tag{1}$$

$$X_i^{t+1} = X_i^t + r_1 \times cos(r_2) \times \left| r_3 P_i^t - X_{ii}^t \right| \tag{2}$$

where X_i^t denotes the positions of the current solution in i_{th} dimension at t_{th} iteration, r_1, r_2, r_3 are three random numbers, P_i denotes the position of the place point in the i_{th} dimension, and || denotes the absolute value (Mirjalili 2016; Fatlawi et al. 2018).

These two equations are connected to be applied as follows:

$$X_i^{t+1} = \begin{cases} X_i^t + r_1 \times sin(r_2) \times \left| r_3 P_i^t - X_i^t \right|, & r_4 < 0.5 \\ X_i^t + r_1 \times cos(r_2) \times \left| r_3 P_i^t - X_{ii}^t \right|, & r_4 \geq 0.5 \end{cases} \tag{3}$$

where r_4 is a random number between [0,1].

As shown in the above equation, there are four central parameters in SCA: r_1, r_2, r_3, and r_4. The parameter r_1 denotes the movement direction of the next position's area. The parameter r_2 denotes to what extent the movement should be towards or outwards from the target. The parameter r_3 denotes a random weight score for the target to stochastically assert ($r_3 >$ 1) or deemphasize ($r_3 <$ 1) the influence of the target in determining the distance. Finally, the parameter r_4 denotes equal switches among the sine and cosine elements, which is indicated in Eq. (3) (Mirjalili 2016).

Because of the value of sine and cosine in this equation, this algorithm is named SCA. The influences of Sine and Cosine on Eqs. (1) and (2) are shown in Fig. 1. This figure shows how the introduced mathematical notations establish a space within two solutions in the available search space. It should be seen that these equations can be increased to higher dimensions despite a two-dimensional paradigm as shown in Fig. 1. The cyclic design of sine and cosine functions support a solution to be relocated around

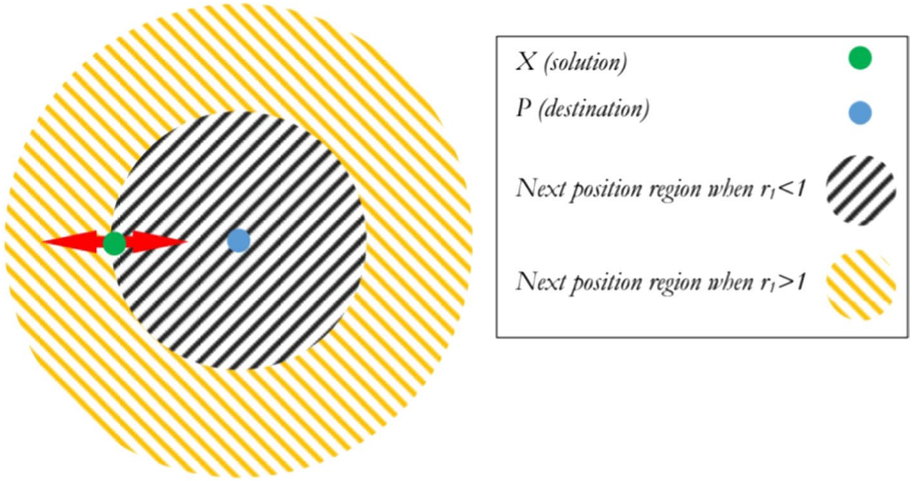


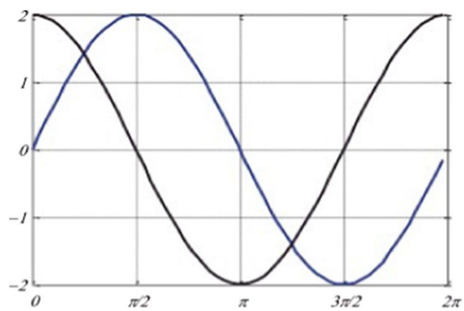
Fig. 1 Effects of Sine and Cosine in Eqs. (1) and (2) in the next position (Mirjalili 2016)

different solutions. This can ensure the search of the exploitation search strategy determined between two solutions. For investigating the search space effectively, the solutions should be capable to search outside the space among their similar destinations as well. This can be accomplished by adjusting the range of the sine and cosine roles as shown in Fig. 2 (Mirjalili 2016; Mirjalili et al. 2020).

A mathematical model of the influences of the sine and cosine functions with the range in $[-2, 2]$ is represented. This mathematical model explains how switching the range area of sine and cosine functions demands a solution to update its positions outside/inside the space within itself and a different solution. The random neighborhood either inside/outside is obtained by specifying a random number for r_2 in $[2, 2\pi]$ in Eq. 3. Consequently, this tool ensures exploration and even exploitation of the search space respectively (Mirjalili 2016; Zou et al. 2018).

Any algorithm should be equipped to balance between exploration and exploitation searches to determine the promising areas of the search space and, finally, to converge optimally to the global optimum. To equipoise exploration and exploitation, the scope of sine and cosine in Eqs. (1), (2) and (3) is modified adaptively by Eq. (4).

Fig. 2 Sine and cosine with a range of $[-2, 2]$ (Mirjalili 2016)



$$r_1 = a - t\frac{a}{T} \tag{4}$$

where t is the number of the current iteration, T is the maximum number of iterations, and a is a constant value.

Figure 3 explains how this equation reduces the range of sine and cosine uses throughout a number of iterations. It may be concluded from Fig. 3 that the SCA explores the available search space while the limits of sine and cosine functions are in $[1, 2]$ and $[-2, -1]$. But, this algorithm, SCA, exploits the search space while the ranges are in between $[-1, 1]$.

After that, the pseudo code of the SCA is shown in Algorithm 1. This figure presents that the SCA begins the optimization procedures by a set of initial random solutions. The algorithm then caches the best solutions achieved so far, specifies it as the destination point (target), and updates other solutions while taking into account the selected best solution. The ranges of sine and cosine functions are refreshed to maintain exploitation of the search space as the iteration number increments. The SCA stops the optimization procedures when the iteration number reaches the maximum number of iterations. However, any other stopping conditions can be taken such as the maximum number of function developments or the precision of the global optimum acquired (Mirjalili 2016; Mirjalili et al. 2020).

Algorithm 1 The Pseudo code of the Sine Cosine Algorithm

Initialize a set of search solutions (X)
Do
    Evaluate each solution by the objective function
    Update the best solution obtained so far ($P = X'$)
    Update r_1, r_2, r_3, and r_4
    Update All positions of the solutions using Equation 3.
While ($t <$ maximum number of iterations)
Return the best-obtained solution so far as global optimum

With the aforementioned procedures, the SCA can probably discover the global optimum of optimization problems because of the following reasons:

- SCA generates and develops a set of random initial solutions for a given optimization problem, so it mainly benefits from strong exploration and local optima eschewal matched to individual-based optimization algorithms.

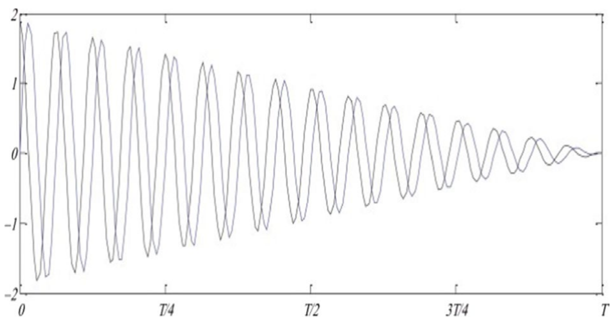


Fig. 3 Decreasing guide for a range of sine and cosine ($a = 3$) (Mirjalili 2016)

- Various areas of the search space are investigated while the sine and cosine functions yield a value larger than 1 or smaller than −1.
- Encouraging areas of the search space are utilized while sine and cosine yield values between −1 and 1.
- The SCA easily transfers from exploration to exploitation search strategies utilizing adaptive range values in the sine and cosine functions.
- The best-obtained global optimum is saved in a variable as the target point and will never become lost through optimization.
- As the solutions update their solution positions close to the best-obtained solution so far, there is a tendency to find the best areas of the search spaces through the optimization process.
- As the SCA considers any optimization problem as black boxes, it is easily incorporable to optimization problems in various fields close to the fitting problem formulation.

3 Variants of Sine Cosine Algorithm

In this section, all variants of the SCA are reviewed in the following subsections. We explain Basic Sine Cosine Algorithms in Sect. 3.1, Chaotic Sine Cosine Algorithms in Section 3.2, Binary Sine Cosine Algorithms in Sect. 3.3, Discrete Sine Cosine Algorithms in Sect. 3.4, Hybrid Sine Cosine Algorithms in Sect. 3.5, Modified Sine Cosine Algorithms in Sect. 3.6, and Multi-objective Sine Cosine Algorithms in Sect. 3.7. Table 1 shows a summary of all variants of the SCA in solving different kinds of optimization problems.

3.1 Basic Sine Cosine Algorithm

Banerjee and Nabi (2017) proposed a new method to address the reentry trajectory problem for a space shuttle vehicle. A charge function, which maximizes the cross-range with satisfying specific terminal conditions, is chosen for addressing this problem. The results showed that the proposed method got better results in term of optimal trajectory, efficiency, and applicability for solving the trajectory controller problem. Kommadath et al. (2017) studied the performance of two optimization algorithms, JAYA and SCA. The IEEE CEC 2014 benchmarks are used to validate the results of the comparisons. The results showed that these two algorithms are competitive. Fatlawi et al. (2018) proposed a new method for addressing the positioning problem. The proposed method is based on SCA which produces various initial random solutions to find the outer side or the optimal way to run. The proposed algorithm got better results in exploring and exploiting the search space.

Pal et al. (2019) proposed a new method, using SCA, to solve nonlinear continuous benchmark functions. The purpose of the proposed method is to examine the influence of the SCA on solving large-scale problems. These results showed that SCA is a powerful algorithm for solving all optimization problems. Elaziz et al. (2019b) proposed an alternative approach to predict ACE Inhibition Activity. The proposed is based on the random vector functional link (RVFL) system based on the SCA to find the optimal arrangement of RVFL. The results showed that the performance of the proposed method is better than other comparative methods.

Table 1 The variants of the Sine Cosine Algorithm

Proposed	Application	Description	Results and conclusion	Year	References
SCA	Trajectory controller problem	Proposed a new method to address the reentry trajectory problem for a space shuttle vehicle	SCA got better results in term of optimal trajectory, efficiency, and applicability	2017	Banerjee and Nabi (2017)
JAYA and SCA	IEEE CEC 2014 benchmarks	Studied the performance of two optimization algorithms JAYA and SCA	The results showed that these two algorithms are competitive	2017	Kommadath et al. (2017)
SCA	The positioning problem	The proposed method is based on SCA, SCA produces various initial random solutions	SCA got better results in exploring and exploiting the search space	2018	Fatlawi et al. (2018)
SCA	Benchmark functions	Proposed a new method, using SCA, to solve nonlinear continuous benchmark functions	SCA is a powerful algorithm for solving all optimization problems	2019	Pal et al. (2019)
SCA	Predict ACE Inhibition Activity	The proposed is based on the random vector functional link (RVFL) system based on the SCA	The performance of the SCA is better than other comparative methods	2019	Elaziz et al. (2019b)
CCSCA	Benchmark functions	Applied chaotic search methods to manage the search space of SCA	CCSCA got better results in terms of global searching ability than the basic SCA	2018	Zou et al. (2018)
CCSCA	Benchmark functions	Added the exhaustive learning mechanism to the whale mechanism and the chaotic SCA operator	CSCWOA got better results in terms of convergence speed, stability, and accuracy	2018	Liu and Li (2018)
CSCA	Engineering application	A novel measuring guide is developed with chaotic SCA optimization	CSCA got better results by an engineering application and comparative testing	2018	Fu et al. (2018b)
SCA	Feature selection	Proposed a new feature selection method based on using SCA	Results showed an improvement compared with other optimization methods	2016	Hafez et al. (2016)

Table 1 (continued)

Proposed	Application	Description	Results and conclusion	Year	References
BSCA	PBUC	The proposed binary SCA applied adjusted sigmoidal function	BSCA is an effective method compared with similar methods	2017	Reddy et al. (2018)
ISCA	Feature selection	Proposed a new method by using SCA with Elitism approach and new update mechanism	ISCA is efficient in obtaining better classification results compared with other similar methods	2017	Sindhu et al. (2017)
MSCA	Truss structures	Proposed a discrete SCA version (MSCA) for addressing discrete optimization problem	MSCA got better results compared with other similar methods	2018	Gholizadeh and Sojoudizadeh (2019)
DSCA	TSP	Proposed a discrete method using SCA (DSCA) to address NP-hard problems	DSCA version is comparable with other similar methods	2018	Tawhid and Savsani (2019a)
DSCA	Networks problems	Proposed a discrete method using SCA (DSCA) to address community detection problems	The results showed that the DSCA is effective and promising	2019	Zhao et al. (2019)
SCA	Feature selection	Proposed a hybrid method to solve the optimization problem	SCA produced better results than other similar methods regarding performance standards and statistical analysis	2017	Elaziz et al. (2017a)
BSA-SCA	Optimal design	Proposed a hybrid method to solve the optimization problem	BSA-SCA is better than other similar comparative algorithms with respect to the statistical test	2017	Turgut (2017)
SCA	DE problems	Proposed a new hybrid technique based on using SCA and Sequential Quadratic Programming	The proposed algorithm outperforms other similar methods regarding the cost and convergence characteristics	2018	Babar and Ahmad (2018)
SCSO	Benchmark functions	Proposed a novel hybrid SCA with particle swarm optimization for solving optimization problems	SCSO got better results in comparison with similar optimization algorithms	2018	Tuncer (2018)

Table 1 (continued)

Proposed	Application	Description	Results and conclusion	Year	References
MOSCA	Engineering problems	Proposed a new hybrid algorithm based on hybridizing the SCA with a multi-orthogonal search strategy	MOSCA is a promising method and got better results compared to similar comparative methods	2018	Rizk-Allah (2018)
PSOSCALF	Functions and engineering problems	Proposed a new hybrid algorithm based on hybridizing SCA with Levy flight	PSOSCALF is successfully utilized to address constrained engineering problems and got better results than other similar methods	2018	Chegini et al. (2018)
SCA-DE	Functions and object tracking	Proposed a new hybrid algorithm based on hybridizing SCA with Differential evolution mechanism	SCA-DE got better results for the benchmark functions and for solving the object tracking, it can track an arbitrary target effectively	2018	Nenavath and Jatoth (2018)
SCCSA	Benchmark functions	Proposed a new hybrid algorithm based on hybridizing SCA with Crow Search Algorithm	SCCSA can give a highly competitive solution compared with other similar methods	2018	Pasandideh and Khalilpourazari (2020)
SCA-FPA	Benchmark functions	Proposed a new hybrid algorithm based on hybridizing SCA with Flower Pollination Algorithm	SCA-FPA got better outcomes than other similar comparative methods	2018	Liu et al. (2018)
ASCA-PSO	Benchmark functions	Proposed a new hybrid algorithm based on hybridizing SCA with particle swarm optimization	The results showed proof of the excellent performance of the proposed ASCA-PSO in terms of computational time and accuracy	2018	Issa et al. (2018)
m-SCA	Benchmark functions	Proposed a new hybrid algorithm based on hybridizing SCA with the opposition based learning	m-SCA is effective in finding the optimal solution for solving the optimization problems	2019	Gupta and Deep (2019a)

Table 1 (continued)

Proposed	Application	Description	Results and conclusion	Year	References
SSCA	Benchmark functions	Proposed a new hybrid algorithm based on hybridizing SCA with the Spiral Optimization Algorithm	The SSCA method converges faster in term of speed compared to other similar comparative methods	2019	Rizal et al. (2019)
SSGA	Engineering design problems	Proposed a new hybrid algorithm based on hybridizing SCA with the steady-state genetic algorithm	SSGA method got better performance compared to other similar optimization methods	2019	El-Shorbagy et al. (2019)
SCA	Power management	Proposed a new multi-objective method combined with an interactive process of SCA	The proposed methods got better results compared with other similar methods	2017	Mahdad and Srairi (2018)
SOA	Benchmark functions	Proposed a new multi-objective method based in SCA, called SOA	The proposed SOA has higher accuracy values to find the global best compared with the basic SCA	2017	Meshkat and Parhizgar (2017a)
SCA	Functions and engineering problems	Proposed a modified version of the SCA that used opposition based learning mechanism for a more careful exploration search	The results showed that the proposed is an efficient method to obtain the optimal solutions in difficult search spaces	2017	Elaziz et al. (2017b)
SCA-PSO	Object tracking	Proposed a novel Hybrid SCA with PSO algorithm for addressing optimization problems	The proposed SCA-PSO for tracking problem got better results in various complex conditions	2018	Nenavath et al. (2018)
SCHLO	Financial markets forecasting	Proposed a modified method using fuzzy time model for business forecasting, which employs the SCA adaptive human learning optimization	The proposed SCHLO is consistently more precise than the other similar comparative methods	2017	Yang et al. (2017)
SCDE	Benchmark functions	Proposed a modified method that combined SCA and mutation operator based on a differential evolution algorithm	The proposed SCDE is able to avert local optima and converge to the global best	2017	Zhou et al. (2017)

Table 1 (continued)

Proposed	Application	Description	Results and conclusion	Year	References
SCA	Network integration	Proposed a new modified SCA to find the optimal maximum energy position tracking (MPPT) algorithm for network integration	The proposed method provided clear, better results compared with other similar methods	2019	Padmanaban et al. (2019)
SCA	Benchmark functions	Proposed a new modified method using SCA to solve several optimizations problems	The results showed that the flexibility of controlling diversity using the proposed algorithm	2018	Zhang et al. (2018b)
SCWWO	Functions and engineering problems	Proposed a new modified method using SCA with water wave optimization algorithm to solve several optimizations problems	The proposed SCWWO enhanced convergence rate and prediction accuracy	2018	Zhang et al. (2018a)
SCA	Benchmark functions	Proposed a new block-matching modified method using SCA with a fitness approximation strategy	The proposed method is compared with other similar methods, and the results showed that the proposed method produced improvements	2018	Dash and Rup (2018)
SCA	Benchmark functions	Proposed a new modified method using SCA with conversion parameter and linear decreasing inertia weight to easily fall out of the local optimum and improves the search area efficiently	The proposed algorithm can efficiently evade from falling into the local optimum, and it has more active convergence activity and higher efficiency	2018	Qu et al. (2018)
SCA	Benchmark functions	Proposed a new modified method using SCA with the PSO algorithm	The results showed superior performances of the proposed LDW-SCSA compared with other similar methods	2018	Tuncer (2020)
SCA	Benchmark functions	Proposed a new modified method using SCA with the quasi-opposition learning in order to initialize the population	The results showed that the proposed algorithm significantly overwhelms compared with other similar methods	2019	Guo et al. (2019)

Table 1 (continued)

Proposed	Application	Description	Results and conclusion	Year	References
HSCA	Benchmark functions	Proposed a new modified method using SCA with the elite-guide evolution strategy in order to initialize the population	The results showed that the proposed HSCA got better results in different cases	2019	Liu et al. (2019)
MO-SCA	Benchmark and engineering problems	Proposed a new multi-objective optimization based on the search technique of SCA	The results showed that the proposed MO-SCA is effectively creating the Pareto front and is simple to execute	2019	Tawhid and Savsani (2019b)
MOSCA	Wind speed forecasting	Proposed a new multi-objective optimization method based on the search technique of SCA and herein-referred	As a decision, it is concluded that the proposed MOSCA can be an effective and powerful method for wind speed forecasting	2018	Wang et al. (2018)
ISCA	Engineering problems	Proposed a new multi-objective optimization method based on the search technique of SCA with multi-bus power systems	The results showed that the proposed ISCA got better results compared to other similar methods	2018	Singh and Tiwari (2018)

3.2 Chaotic Sine Cosine Algorithm

Zou et al. (2018) proposed a new method, Chaos Cultural Sine Cosine Algorithm called CCSCA, to solve the premature convergence in SCA. The proposed method used a cultural algorithm as the structure of the population and applied chaotic search methods to manage the search space. The results of benchmark functions showed that the proposed CCSCA got better results in terms of global searching ability than the basic SCA to avert the premature appearance.

Liu and Li (2018) proposed a new method, Whale optimization algorithm based on chaotic sine cosine operator called CSCWOA, to solve the premature convergence. The proposed method added the exhaustive learning mechanism to the whale mechanism and the chaotic sine cosine operator through the searching process. The results proved that the proposed algorithm got better results in terms of convergence speed, stability, and accuracy. Fu et al. (2018b) proposed a novel measuring guide for the vibrational aim of a hydropower generator (HPG) using optimal variational mode decomposition (OVMD) and a least-squares support vector machine (VSM) developed with chaotic SCA optimization (CSCA). The results showed that the proposed method got better results by an engineering application and comparative testing.

3.3 Binary Sine Cosine Algorithm

Feature selection is one of the most common problems in the machine learning domain (Abualigah 2019b; Abualigah et al. 2018). Hafez et al. (2016) proposed a new feature selection method based on using SCA. SCA adaptively adjusts the exploration and exploitation to determine the optimal solution quickly. The proposed method was examined on 18 benchmark datasets and showed an improvement compared to other optimization methods such as particle swarm optimization (PSO) and genetic algorithm (GA). Reddy et al. (2018) proposed a binary SCA, called BSCA, for solving the profit-based unit commitment (PBUC) problem. The proposed binary SCA applied adjusted sigmoidal functions for binary mapping of continuous search space. The results showed that the proposed BSCA is an effective method compared with similar methods for solving PBUC. Sindhu et al. (2017) proposed a new method, using SCA with Elitism approach and a new update mechanism called ISCA, to choose the best attributes/features to enhance the classification precision. The proposed method was examined with 10 benchmark datasets and the results showed that ISCA is efficient in obtaining better classification results compared to other similar methods.

3.4 Discrete Sine Cosine Algorithm

Gholizadeh and Sojoudizadeh (2019) proposed a discrete SCA version (MSCA) for addressing discrete optimization problem (truss structures). The performance of the proposed MSCA is demonstrated through multiple benchmark truss structures problems. The proposed algorithm got better results compared with other similar methods. Tawhid and Savsani (2019a) proposed a discrete method using SCA (DSCA) to address NP-hard problems [the traveling salesman problem (TSP)]. To adjust the exploration and exploitation in the proposed DSCA, two various mathematical expressions are utilized to update the solutions' positions. TSPLIB benchmarks are selected to test the proposed

DSCA, and the results showed that the DSCA version is comparable with other similar methods. Zhao et al. (2019) proposed a discrete method using SCA (DSCA) to address community detection problems. DSCA is compared with other similar optimization algorithms on four real-world networks problems. The results showed that the DSCA is effective and promising.

3.5 Hybrid Sine Cosine Algorithm

Elaziz et al. (2017a) proposed a hybrid method to solve optimization problems (i.e., feature selection). The proposed method is based on hybridizing SCA with local search strategy (the differential evolution mechanisms). The results showed that the proposed method produced better results than other similar methods regarding performance standards and statistical analysis. Turgut (2017) proposed a hybrid method to solve the optimization problem called BSA-SCA. The proposed method is based on using the combination of the advantages of the backtracking search (BSA) and SCA to obtain the optimal design of a shell and tube evaporator problem. Comparison results showed that solutions from the proposed BSA-SCA are better than other similar comparative algorithms with respect to the statistical test. Babar and Ahmad (2018) proposed a new hybrid technique based on using SCA and Sequential Quadratic Programming to address Electrical Dispatch (ED) problems. The proposed algorithm tested 40 unit IEEE test modes with transmission losses. The results showed that the proposed algorithm outperforms other similar methods regarding the cost and convergence characteristics.

Tuncer (2018) proposed a novel hybrid SCA with particle swarm optimization for solving optimization problems called SCSO. In SCSO, firstly particles are created randomly in the available search space. In order to test the performance of the SCSO, 14 benchmark functions are utilized and the results showed that the proposed SCSO got better results in comparison with similar optimization algorithms. Rizk-Allah (2018) proposed a new hybrid algorithm based on hybridizing the SCA with a multi-orthogonal search strategy (MOSCA) for addressing engineering design problems. The proposed MOSCA combines the benefits of both algorithms to eliminate SCA disadvantages. The performance of the proposed MOSCA is examined by utilizing 18 benchmark functions and 4 engineering problems. The results showed that the proposed MOSCA is a promising method and got better results compared to similar comparative methods. A new method is proposed in Gupta and Deep (2019b) to alleviate the issues from SCA by introducing an enhanced variant of SCA called HSCA. The proposed HSCA changes the search mechanism of basic SCA by combining and hybridizing it with a simulated algorithm. Moreover, the proposed HSCA is further utilized for training multilayer perceptrons. The obtained results demonstrated the advantage of the HSCA matched to other comparative methods.

Chegini et al. (2018) proposed a new hybrid algorithm based on hybridizing SCA with Levy flight (PSOSCALF) to address optimization problems. The results of the benchmark functions showed that the proposed PSOSCALF is more successful than other similar methods in defining the global minimum of certain functions. Moreover, the proposed PSOSCALF is successfully utilized to address constrained engineering problems and got better results than other similar methods. Nenavath and Jatoth (2018) proposed a new hybrid algorithm based on hybridizing SCA with Differential evolution mechanism (SCA-DE) for addressing optimization problems and object tracking. The performance of the proposed SCA-DE is assessed using 23 benchmark functions and a real case study (object tracking). The results showed that the SCA-DE got better results for the benchmark functions and for solving the object tracking; it can track an arbitrary target more effectively in different hard conditions than other similar trackers.

Pasandideh and Khalilpourazari (2020) proposed a new hybrid algorithm based on hybridizing SCA with Crow Search Algorithm (SCCSA) to solve optimization problems. The aggregate of ideas and operators of both algorithms allows the proposed SCCSA to produce a proper trade-off between exploration and exploitation capabilities. To assess the performance of the SCCSA, 7 benchmark functions are used. The results showed that the proposed SCCSA can give a highly competitive solution compared with other similar methods. Liu et al. (2018) proposed a new hybrid algorithm based on hybridizing SCA with Flower Pollination Algorithm (SCA-FPA) to solve optimization problems. The proposed method designed the SCA to act as a local search operator in Flower Pollination Algorithm to avoid the local optimum problem. Six benchmark functions are examined to validate the results of the proposed DEFPA, and the results showed that the proposed SCA-FPA got better outcomes than other similar comparative methods. Issa et al. (2018) proposed a new hybrid algorithm based on hybridizing SCA with particle swarm optimization to solve optimization problems, called ASCA-PSO. The proposed ASCA-PSO is tested using different benchmark functions, which showed its superiority compared with other similar methods. The results showed proof of the excellent performance of the proposed ASCA-PSO in terms of computational time and accuracy.

Gupta and Deep (2019a) proposed a new hybrid algorithm based on hybridizing SCA with the opposition based learning to solve real-world optimization problems, called m-SCA. To assess the performance of the proposed method in addressing the global optimization problems, two sets of benchmark functions are used: 23 benchmark problems and IEEE CEC 2014 benchmark problems. The results showed that the proposed m-SCA is effective in finding the optimal solution for solving the optimization problems. Rizal et al. (2019) proposed a new hybrid algorithm based on hybridizing SCA with the Spiral Optimization Algorithm to solve real-world optimization problems, called SSCA. The results showed that the proposed SSCA method significantly outperformed the basic SCA. Moreover, the SSCA method converges faster in term of speed compared to other similar comparative methods. El-Shorbagy et al. (2019) proposed a new hybrid algorithm based on hybridizing SCA with the steady-state genetic algorithm to address engineering design problems, called SSGA. This method combines the advantages of the exploration ability of SCA and exploitation ability of the genetic algorithm to evade the early convergence. The results showed that the proposed SSGA method got better performance compared to other similar optimization methods for solving two hard engineering design problems.

3.6 Modified Sine Cosine Algorithm

Mahdad and Srairi (2018) proposed a modified method combined with an interactive process of SCA to enhance the energy system security regarding charging margin balance. The proposed method is validated using the IEEE 30-bus and the IEEE 118-bus. The results showed that the proposed methods got better results compared with other similar methods. Meshkat and Parhizgar (2017a) proposed a new modified method based in SCA called SOA. The proposed method and updated position of solutions is arranged randomly by the best solution of the random search solutions. The results showed that the proposed SOA has higher accuracy values to find the global best compared with the basic SCA, while additionally having a more stable convergence rate.

Elaziz et al. (2017b) proposed a modified version of the SCA that used an opposition-based learning mechanism for a more careful exploration search to produce more precise solutions. The proposed modified SCA used two optimization problems: benchmark functions and engineering problems. The results showed that the proposed method is an efficient approach to obtain the optimal solutions in difficult search spaces. Nenavath et al. (2018) proposed a novel Hybrid SCA with PSO algorithm for addressing optimization problems such as object tracking that is called SCA-PSO. The proposed method connects the exploitation ability of PSO and exploration ability of SCA to produce the optimal solution. The performance of this algorithm is assessed using CEC 2005, 23 classical, and CEC 2014 functions. The results showed that the proposed SCA-PSO for tracking problem got better results in various complex conditions.

Zhou et al. (2017) proposed a modified method that combined SCA and mutation operators based on a differential evolution algorithm, named SCDE. The proposed method aims to trade-off between exploration and exploitation. The proposed SCDE is compared with other similar methods using benchmark functions. The results showed that the proposed SCDE is able to avert local optima and converge to the global best. Padmanaban et al. (2019) proposed a new modified SCA to find the optimal maximum energy position tracking (MPPT) algorithm for network integration. The proposed method gives the maximum power from a photovoltaic (PV) panel and reduced implementation with a privilege of high convergence speed. The results showed that the proposed method provided clear better results compared with other similar methods.

Zhang et al. (2018b) proposed a new modified method using SCA to solve several optimizations problems. The searchability of the proposed method declines when handling difficult problems due to early convergence. 29 benchmark functions are executed to assess algorithm performance. The results showed flexibility in controlling diversity using the proposed algorithm, and it is an encouraging method to be utilized with other similar algorithms. Dash and Rup (2018) proposed a new block-matching modified method using SCA with a fitness approximation strategy to solve several optimizations problems (benchmark functions and structural engineering design problems), called SCWWO. The proposed method is compared with other similar methods, and the results showed that the proposed method produced improvements over other sufficient schemes.

Guo et al. (2019) proposed a new modified method using SCA with quasi-opposition learning in order to initialize the population for addressing several optimizations problems. Moreover, the proposed method is combined with quasi-opposition learning strategy and opposition-based learning approaches to improve the efficacy of global exploration and enhance the convergence rate. 23 benchmark functions were used to test the performance of the proposed method. The results showed that the proposed algorithm significantly overwhelms others when it is compared to similar methods. Liu et al. (2019) proposed a new modified method using SCA with the elite-guide evolution strategy in order to initialize the population to solve several optimizations problems (complex peak operation problems), called HSCA. The results showed that the proposed HSCA got better results in different cases, and that it can generate scheduling outcomes with higher quality than other similar methods.

3.7 Multi-objective Sine Cosine Algorithm

Tawhid and Savsani (2019b) proposed a new multi-objective optimization based on the search technique of SCA, named MO-SCA. It uses the elitist non-dominated sorting and crowding measure for getting several non-domination levels and to protect the variety between the optimal set of solutions, respectively. The results showed that the proposed MO-SCA is effectively creating the Pareto front and is simple to execute. Wang et al. (2018) proposed a new multi-objective optimization method based on the search technique of SCA and herein-referred for solving several optimization problems, named MOSCA. The results clearly showed that the multi-objective forecasting system is better compared to all similar comparative methods in terms of accuracy and stability. As a decision, it is concluded that the proposed MOSCA can be an effective and powerful method for wind speed forecasting. Singh and Tiwari (2018) proposed a new multi-objective optimization method based on the search technique of SCA with multi-bus power systems for solving several optimization problems (controlling the various parameters of the power system), named ISCA. The IEEE 30-bus examination system is analyzed to verify the proposed ISCA method for optimal allocation of holomorphic embedded load-flow (HELF) patterns. The results showed that the proposed ISCA got better results compared to other similar methods.

4 Applications of Sine Cosine Algorithm

SCA is used effectively to tackle different optimization problems in various fields such as machine learning, engineering design problems, and others. We explain benchmark functions using the Sine Cosine Algorithms in Sect. 4.1, engineering applications using the Sine Cosine Algorithms in Sect. 4.2, image processing using the Sine Cosine Algorithms in Sect. 4.3, machine learning applications using the Sine Cosine Algorithms in Sect. 4.4, networks applications using the Sine Cosine Algorithms in Sect. 4.5, parameters setting using the Sine Cosine Algorithms in Sect. 4.6, and scheduling applications using the Sine Cosine Algorithms in Sect. 4.7. Table 2 shows a summary of all applications of the SCA in solving several optimization problems.

4.1 Benchmark functions

Meshkat et al. (2017b) proposed a new update position approach instead of the original position update approach of the SCA. In order to evaluate the effectiveness of the proposed method, a collection of benchmark functions is utilized. The results showed that the proposed method got higher accuracy in obtaining the global optimum, and the proposed method can converge quicker compared to other similar methods. Ekiz (2017) proposed a new optimization method using the original SCA for solving constrained optimization problems. To evaluate the effectiveness of the proposed method, a collection of benchmark functions is utilized and compared with GA and PSO algorithm. The comparative results showed that the SCA got higher accuracy in obtaining the global optimum compared to other similar methods. Zhang et al. (2017) proposed an enhanced method using SCA by introducing dynamic inertia weight and adjusting the algorithm for the local and global search, called ISCA. The proposed method is evaluated using 10 benchmark functions with different characterizations. The results showed that the proposed ISCA algorithm is better than other similar comparative methods.

Jusof et al. (2018) proposed a new method using the Kalman-Filter-based SCA by introducing a synergy of a Simulated Kalman Filter algorithm (random based optimization method) for solving several optimization problems, called KFSCA. The proposed KFSCA

Table 2 The applications of the Sine Cosine Algorithm

Proposed	Application	Description	Results and conclusion	Year	References
SCA	Benchmark functions	Proposed a new update position approach instead of the original position update approach of the SCA	The results showed that the proposed method got higher accuracy in obtaining the global optimum, and the proposed method can converge quicker compared to other similar methods	2017	Meshkat et al. (2017b)
SCA	Benchmark functions	Proposed a new optimization method using the original SCA for solving constrained optimization problems	The comparative results showed that the SCA got higher accuracy in obtaining the global optimum compared to other similar methods	2017	Ekiz (2017)
ISCA	Benchmark functions	Proposed an enhanced method using SCA by introducing dynamic inertia weight and adjusting the algorithm for the local and global search	The proposed ISCA algorithm is better than other similar comparative methods	2017	Zhang et al. (2017)
KFSCA	Benchmark functions	Proposed a new method using the Kalman-Filter-based SCA by introducing a synergy of a Simulated Kalman Filter algorithm	The proposed KFSCA got better accuracy and outperformed the comparative methods	2018	Jusof et al. (2018)
SCA-OPI	Functions and engineering problems	Proposed a novel SCA based on parallel learning for solving several optimization problems	The proposed SCA-OPI can produce a high performance compared with other similar methods	2019	Rizk-Allah (2019)
iSCA	Benchmark functions	Proposed an extensive version of SCA to overcome the local minima trapping in solving optimization problems	The proposed iSCA is a very competitive method compared to the other similar optimization methods	2018	Suid et al. (2018)
QSCA	Benchmark functions	Proposed a quaternion based-SCA for solving several optimization problems	The proposed QSCA algorithm obtained better results in terms of global optimization strength and higher accuracy	2019	Lv et al. (2019)

Table 2 (continued)

Proposed	Application	Description	Results and conclusion	Year	References
CSCA	Benchmark functions	Proposed a cloud model based-SCA for solving several optimization problems	The proposed CSCA is superior compared to other similar comparative methods in terms of scalability and robustness	2019	Cheng and Duan (2019)
SCA	Benchmark functions	Proposed an enhanced SCA method with a novel adaptive strategy based on an exponential phase	The proposed method got a significant improvement in terms of the precision and convergence rate	2019	Jusof et al. (2019)
ISCA	Benchmark functions	Proposed a novel enhanced version of SCA, which improves the exploitation ability of candidate solutions	The proposed ISCA is an efficient method in solving optimization problems	2019	Gupta and Deep (2019c)
ISCA	Benchmark functions	Proposed a new method based on modified SCA to solve several optimization problems	The proposed ISCA is a competitive method for high-dimensional problems compared with other similar optimization methods	2019	Long et al. (2019)
SCA-SM	Benchmark functions	Proposed a new method that incorporates the features of SCA and the Simpson system	The proposed SCA-SM gives an effective way to determine the numerical value of particular integrals, and it got a high convergence speed and high precision	2019	Abdel-Baset et al. (2019)
EBS-SCA	Functions and real-world problems	Proposed a new method based on using enhanced brainstorm and the SCA	The proposed EBS-SCA method got the best performance in terms of the global optimum, convergence rate, and scalability	2019	Li et al. (2019)
ASCA-DE	Engineering problems	Proposed an extended SCA to be self-adaptive and its generation operators are combined with the mutation mechanism of differential evolution strategies	The proposed ASCA-DE outperformed the other similar optimization algorithms	2017	Bureerat and Pholdee (2017)

Table 2 (continued)

Proposed	Application	Description	Results and conclusion	Year	References
SCA	Engineering problems	Proposed a new method using the elimination of major lower-order 5_{th} consonant based on the SCA	The proposed method efficiently reduces the prespecified 5_{th} consonant with decreased total harmonic distortion	2017	Sahu and Londhe (2017)
SCA	Engineering problems	Proposed a new method using SCA for solving the economic load dispatch problems	The proposed method clearly got better results in comparison with other similar methods	2017	Yulianto et al. (2017)
SCA	Engineering problems	UPQC is solved by SCA to reduce the wastes and increase the voltage outline	The proposed algorithm got better results in terms of power losses	2017	Ramanaiah and Reddy (2017)
	Engineering problems	Proposed a powerful SCA method to describe the ELD problem in terms of balance and difference restrictions	The proposed algorithm overcomes the other similar optimization methods	2018	Bhattacharjee and Patel (2020)
SCA	Engineering problems	Proposed a novel method using SCA to find the optimal placement of the PMU's in energy usage visibility	The results showed the ability of SCA in finding better results	2018	Laouamer et al. (2018)
SCA	Engineering problems	Proposed a novel method using SCA to address the unit engagement problem	The applicability of the proposed method	2018	de Oliveira et al. (2018)
SCA	Engineering problems	Proposed a fuzzy logic PID controller optimized by enhanced SCA for the load frequency control	The proposed ISCA tuned the controller and it has superior production	2019	Rajesh and Dash (2019)
SCA-ANFIS	Engineering problems	Proposed a new method for solving oil waste forecasting by increasing the ANFIS using the SCA	The proposed SCA-ANFIS method outperforms the other similar methods	2018	Al-Qaness et al. (2018)
SCAPSS	Engineering problems	Proposed a new method based on the SCA	The proposed SCAPSS performed better than other similar methods	2019	Ekinci (2019)

Table 2 (continued)

Proposed	Application	Description	Results and conclusion	Year	References
MSCA	Engineering problems	Proposed a novel modified method based on using SCA for solving the optimal power flow (OPF) problem	The proposed MSCA is an effective method compared with other similar methods	2018	Attia et al. (2018)
MSCA	Engineering problems	Proposed a new modified method for solving the Optimal Reactive Power Dispatch Problem	The results showed the superiority and effectiveness of the proposed MSCA	2019	Abdel-Fatah et al. (2019)
SCA	Engineering problems	Proposed a method for solving the multi-objective problem using SCA	The results showed that the proposed method got better results than similar comparative methods	2019	Shukla et al. (2019)
SCA	Engineering problems	Proposed a new extended SCA to solve combined economic and emission dispatch problems	The proposed SCA produces high-quality solutions and exceeds other similar optimization methods	2019	Gonidakis and Vlachos (2019)
MSCA	Engineering problems	Proposed a new extended to produce the standard PID and fuzzy-PID handlers	The proposed MSCA got small sensitive parametric changes	2019	Nayak et al. (2019)
	Engineering problems	Proposed a modified version of SCA to enhance the handler parameter	The M-SCA presented the highest total power generation	2019	Suid et al. (2019)
SCA	Image processing	Proposed a new method to examine the influences of SCA on decreasing the consolidated K-means clustering	The proposed method got the highest rate than other similar methods in terms of F-measure, Pseudo-F-measure, and other measures	2016	Elfattah et al. (2016)
ALO-SCA	Image processing	Proposed a new method using Antlion Optimizer (ALO) and SCA with two standard thresholds rules	The proposed methods do not exceed other similar methods	2018	Oliva et al. (2018)
SCA-RELM	Image processing	Proposed a new method for mechanical examination of diseased brain utilizing MRI	The proposed SCA-RELM method is examined using other similar methods for single-layer feed-forward NN	2018	Nayak et al. (2018a)

Table 2 (continued)

Proposed	Application	Description	Results and conclusion	Year	References
SCA	Machine learning	Proposed an improved method to train and update the importance and the preferences of the network to give the optimum value	The performance of the proposed model is better and more efficient than other similar methods	2019	Sahlol et al. (2016)
SCA	Machine learning	Proposed the application of SCA for training an artificial neural network (ANN) in the problem of trust forecasting	GA still outperforms SCA under the same testing elements	2017	Hamdan et al. (2017)
OSCA	Machine learning	Proposed an Opposition-Based SCA for solving feed-forward NN training	The results showed that the proposed method got better results compared with other similar methods	2017	Bairathi and Gopalani (2017)
CQSCA	Machine learning	Proposed a novel hybrid error examination pattern with entropy feature extraction and SVM optimized by the SCA	The proposed CQSCA produced the best training accuracy of 99.5% and the largest testing accuracy of 97.89%	2018	Fu et al. (2018a)
MSCA-ELM	Machine learning	Proposed a new computerized system for the discovery of the pathological brain through MRI	The proposed MSCA-ELM method can recognize the diseased brain in real-time and can be connected on medical robots	2018	Nayak et al. (2018b)
ASOSCA	Machine learning	Proposed a new method for data clustering using hybrid atom search optimization (ASO) and SCA	The proposed ASOSCA got high superiority compared to other similar methods in terms of clustering criteria	2019	Elaziz et al. (2019a)
ISCA	Machine learning	Proposed a new enhanced SCA for solving the feature selection problem	The proposed ISCA got a high performance compared with other similar methods	2019	Belazzoug et al. (2020)
SCA	Machine learning	Several criteria are utilized to forecast with SCA to select the most suitable samples after NN training	The proposed method can achieve a lower forecast error compared with other similar methods	2019	Rahimi (2019)

Table 2 (continued)

Proposed	Application	Description	Results and conclusion	Year	References
SCA	Networks applications	Proposed a method using SCA for choosing the optimal choice of leaders in radial configuration networks	The proposed method got effective performance in overcoming the network losses while keeping the particularized restrictions	2017	Ismael et al. (2017)
SCA	Networks applications	Proposed a method for solving the breast cancer analysis utilizing a supply preface NN trained by the SCA	The proposed SCA-NN is very strong, effective and got better correct analysis compared to other similar methods	2018	Majhi (2018)
SCA	Networks applications	Proposed a method that used SCA in routing and clustering for improving the working life of WSNs	The results showed the ability of the proposed method at various locations	2018	Pandey et al. (2018)
SCA	Networks applications	Proposed an improved method using SCA for addressing the problem of the power distribution network reconfiguration	The results showed the superiority of the proposed method	2019	Raut and Mishra (2019)
SCA	Parameters setting	Proposed a novel approach for loss of higher-order constant systems using SCA	The proposed method outperformed other similar methods	2017	Singh (2017)
SCA-SVR	Parameters setting	Proposed a new method using support vector regression to solve time series prediction problems	The proposed SCA-SVR method proved to be achievable efficiently and likely	2018	Li et al. (2018)
SCA	Parameters setting	Proposed a comparative study to examine the parameters of PV-cell using Whale Optimization Algorithm (WOA) with SCA	The results showed the ability of the proposed method in solving this problem	2019	Aydin et al. (2019)
SCA	Scheduling applications	Proposed a new method using the SCA to solve the problem of short-term hydrothermal scheduling	The proposed SCA produced superior results	2017	Das et al. (2018)

Table 2 (continued)

Proposed	Application	Description	Results and conclusion	Year	References
HSCA	Scheduling applications	Proposed a new hybrid method using the SCA to solve the carbon emissions problem	The proposed HSCA got better performance compared to other similar methods	2018	Utama (2019)
SCA	Scheduling applications	Proposed a new hybrid method to solve the problem of optimal allocation and hourly scheduling of capacitor banks	The superiority of the proposed method was demonstrated by comparing its results with other similar methods	2019	Abdelsalam and Mansour (2019)

is tested with different benchmark functions and compared with other similar comparative methods. The results showed that the proposed KFSCA got better accuracy and outperformed the comparative methods. Suid et al. (2018) proposed a novel SCA based on parallel learning for solving several optimization problems, called SCA-OPI. In the proposed SCA-OPI, multiple-orthogonal parallel learning is presented to show effectively two benefits: keep the diversity of the solutions and improve the exploration search. The proposed SCA-OPI algorithm is assessed and examined using benchmark functions and engineering applications. The results showed that the proposed SCA-OPI can produce a high performance compared with other similar methods, especially in terms of reliability.

Rizk-Allah (2019) proposed a novel SCA based on parallel learning for solving several optimization problems, called SCA-OPI. In the proposed SCA-OPI, multiple-orthogonal parallel learning is presented to show effectively two benefits: keep the diversity of the solutions and improve the exploration search. The proposed SCA-OPI algorithm is assessed and examined using benchmark functions and engineering applications. The results showed that the proposed SCA-OPI can produce a high performance compared with other similar methods, especially in terms of reliability. Lv et al. (2019) proposed a quaternion based-SCA for solving several optimization problems, called QSCA. The proposed QSCA added the concept of coding individuals with quaternions. The proposed QSCA is tested using 5 benchmark functions. The results showed that the proposed QSCA algorithm obtained better results in terms of global optimization strength and higher accuracy.

Cheng and Duan (2019) proposed a cloud model based-SCA for solving several optimization problems, called CSCA. In proposed CSCA, the cloud paradigm is applied to improve the charge parameter adaptively while running SCA framework unchanged. The production of the proposed CSCA method is assessed using 13 benchmark functions with different characterizations. The results showed that the proposed CSCA is superior compared to other similar comparative methods in terms of scalability and robustness. Jusof et al. (2019) proposed an enhanced SCA method with a novel adaptive strategy based on an exponential phase. The exponential phase is utilized to build a connection between searching for solutions and fitness functions. The proposed method is examined using benchmark functions and compared with the basic SCA. The results showed that the proposed method got a significant improvement in terms of the precision and convergence rate.

Gupta and Deep (2019c) proposed a novel enhanced version of SCA, called ISCA, which improves the exploitation ability of candidate solutions and decreases the excess of diversity existing in the search equations of the basic SCA. To evaluate the proposed ISCA, a set of benchmark functions is utilized, and the results showed that the proposed ISCA is an efficient method in solving optimization problems compared with other similar methods. Long et al. (2019) proposed a new method based on modified SCA to solve several optimization problems, called ISCA. The proposed ISCA used a new adjusted position-updating model to stimulate the SCA convergence. Moreover, a new nonlinear decreasing growth parameter approach is produced to support exploration and exploitation search. The performance of the proposed ISCA is examined using 24 benchmark functions and several engineering problems. The results showed that the proposed ISCA is a competitive method for high-dimensional problems compared with other similar optimization methods. Li et al. (2019) proposed a new method based on using enhanced brainstorm and the SCA, called EBS-SCA. The proposed EBS-SCA employed the brainstorm to enhance population diversity. 46 benchmark functions and two real-world problems are used to validate the results of the proposed EBS-SCA. The results showed that the proposed EBS-SCA method got the best performance in terms of the global optimum, convergence rate, and scalability. Other related papers can be found in Gupta and Deep (2019b) and Gupta et al. (2019).

4.2 Engineering applications

Bureerat and Pholdee (2017) proposed an extended SCA to be self-adaptive and its generation operators are combined with the mutation mechanism of differential evolution strategies, called ASCA-DE. The proposed ASCA-DE is an adaptive SCA blended with differential evolution and applied to address optimization problems for architectural damage discovery. The results showed that the proposed ASCA-DE outperformed the other similar optimization algorithms.

Sahu and Londhe (2017) proposed a new method using the elimination of major lower-order 5_{th} consonant in cascaded five-level inverters based on the recently launched SCA. The proposed method efficiently reduces the pre-specified 5_{th} consonant with decreased total harmonic distortion. Yulianto et al. (2017) proposed a new method using SCA for solving the economic load dispatch (ELD) problems for steam power plants. The results showed that the proposed method clearly got better results in comparison with other similar methods. Ramanaiah and Reddy (2017) proposed a novel idea of Unified Power Quality Conditioner (UPQC). The dilemma of UPQC organization is expressed as an individual objective problem. UPQC is solved by SCA to reduce the wastes and increase the voltage outline. The proposed method has experimented on standard distribution systems, and the results showed that the proposed algorithm got better results in terms of power losses.

Bhattacharjee and Patel (2020) proposed a powerful SCA method to describe the ELD problem in terms of balance and difference restrictions. The main purpose of ELD is to provide the entire ELD at the smallest cost. The results showed that the proposed algorithm overcomes the other similar optimization methods in terms quality of the obtained-solution, robustness, and computational performance. Laouamer et al. (2018) proposed a novel method using SCA to find the optimal placement of the PMU's in energy usage visibility. The PMU placement problem is designed for reducing the number of PMUs ordering in the energy grid. The proposed new method of placement is evaluated using 3 standards: IEEE-9, 14, and 30-buses. The results showed the ability of SCA to find better results. de Oliveira et al. (2018) proposed a novel method using SCA to address the unit engagement problem associated with thermoelectric production units in an electrical energy arrangement. The proposed method is assessed in its original form and by using SCA based on sensitivity criteria. Experiments are conducted using case studies with two examination systems and the results showed the applicability of the proposed method and the performance of optimization methods for solving multimodal optimization problems.

Rajesh and Dash (2019) proposed a fuzzy logic PID controller optimized by enhanced SCA for the load frequency control (LFC) of an independent energy production system, called ISCA. The balance of the proposed control method is examined using Eigenvalue investigations. Eventually, the results show that the proposed ISCA tuned the controller and it has superior production compared with conventional PID controller. Al-Qaness et al. (2018) proposed a new method for solving oil waste forecasting by increasing the ANFIS using the SCA, called SCA-ANFIS. In the proposed SCA-ANFIS, the adjustment parameters of the adaptive neuro-fuzzy thought system are determined using the SCA. To evaluate the effectiveness of the proposed SCA-ANFIS method, a real dataset of petroleum products is used. The results showed that the proposed SCA-ANFIS method outperforms the other similar methods.

Ekinci (2019) proposed a new method based on the SCA that supports exploration and exploitation ability called SCAPSS. The results showed that the proposed SCAPSS performed better than other similar methods regarding the quality of solutions and converge rate. Attia et al. (2018) proposed a novel modified method based on using SCA for solving the optimal power flow (OPF) problem, called MSCA. The proposed MSCA aims at decreasing the running time with sufficient development in determining the optimal solution and probability. The MSCA is verified using benchmark systems under chosen objective costs. The results showed that the proposed MSCA is an effective method compared with other similar methods. Abdel-Fatah et al. (2019) proposed a new modified method for solving the Optimal Reactive Power Dispatch Problem, called MSCA. The modified SCA (MSCA) is based on using the Levy flight arrangement with an adaptive mechanism. The proposed MSCA is used to the IEEE 30-bus and the produced results are compared with other similar methods. The results showed that the superiority and effectiveness of the proposed MSCA.

Shukla et al. (2019) proposed a method for solving the multi-objective problem using SCA. The proposed method works to get the frame of the quadrilateral relay. The performance of the proposed method in terms of giving optimal setting is examined against a wide variety in error parameters and operating situations. The results showed that the proposed method got better results than similar comparative methods. Gonidakis and Vlachos (2019) proposed a new extended SCA to solve combined economic and emission dispatch problems. The proposed method is illustrated by a trigonometric-based design and used three analysis systems with various features. The results showed that the proposed SCA produces high-quality solutions and exceeds other similar optimization methods. Suid et al. (2019) proposed a modified version of SCA to enhance the handler parameter of an arrangement of turbines such that the whole power generation of a wind plant is enhanced, called M-SCA. The two adjustments applied to the basic SCA are in terms of the renewed step volume gain and the updated configuration variable. The statistical production investigation showed that the M-SCA presented the highest total power generation compared with other similar methods.

4.3 Image processing

Image processing is the use of a digital computer to process digital images using an algorithm (Gupta and Deep 2019a). Elfattah et al. (2016) proposed a new method to examine the influences of SCA on decreasing the consolidated K-means clustering technique as the objective function. The SCA seeks the optimal clustering of the presented handwritten image into compressed clusters following some restrictions. The result showed that the proposed method got the highest rate over other similar methods in terms of F-measure, Pseudo-F-measure, and other measures. In this paper Gupta and Deep (2019a), an endeavor has been performed to the elimination of the drawbacks of the basic ABC by offering a novel hybrid technique called the SCABC algorithm. The proposed SCABC hybridizes the ABC with the SCA to enhance the level of search in the basic ABC algorithm. The validation of the proposed SCABC is conducted on a benchmark set of 23 optimization problems. The different performance tests illustrate the effectiveness of the proposed SCABC algorithm in defining the optimal thresholds of images.

Oliva et al. (2018) proposed a new method using Antlion Optimizer (ALO) and SCA with two standard thresholding rules to make multilevel thresholding for the energy curve in image segmentation. The proposed method is tested concerning the feature, and the statistical investigation is performed to analyze the results of the proposed algorithm compared with similar methods. The results showed that the proposed methods do not exceed other similar methods. Nayak et al. (2018a) proposed a new method for mechanical examination of diseased brains utilizing magnetic resonance imaging (MRI). The proposed method hybridized regularized ultimate learning mechanism and SCA (SCA-RELM) works to overcome the disadvantages of conventional systems and other traditional learning algorithms. The performance of the proposed SCA-RELM method is examined using other similar methods for single-layer feed-forward NN.

4.4 Machine learning applications

Sahlol et al. (2016) proposed an improved method, the forecast precision of organ enzymes of fish supplied by generating a neural network pattern based on the SCA, to train and update the importance and the preferences of the network to give the optimum value. The results showed that the performance of the proposed model is better and more efficient than other similar methods. Hamdan et al. (2017) proposed the application of SCA for training an artificial neural network (ANN) in the problem of trust forecasting. The knowledge utilized in this paper is gathered over 3 years, i.e., 2014-2016. The results showed that SCA and GA got good performance and present good fitting for the reduced data and good forecast; nevertheless, GA still outperforms SCA under the same testing elements. Bairathi and Gopalani (2017) proposed an opposition-based SCA for solving feed-forward NN training, called OSCA. OSCA is a new meta-heuristic algorithm, which is an enhanced version of SCA and manages the opposition-based learning for better search. The results showed that the proposed method got better results compared with other similar methods.

Fu et al. (2018a) proposed a novel hybrid error examination pattern with entropy feature extraction and SVM optimized by the SCA, called CQSCA. The results showed that the proposed CQSCA produced the best training accuracy of 99.5% and the largest testing accuracy of 97.89%. Moreover, it can be achieved from the figures of various examination techniques that the balance and accuracy of the proposed system are better than other similar methods. Nayak et al. (2018b) proposed a new computerized system for the discovery of the pathological brain through MRI. A novel training strategy entitled as advanced learning machine with modified SCA (MSCA-ELM) is introduced by mixing ELM and MSCA for analysis of MR images. The proposed MSCA-ELM method can recognize the diseased brain in real-time and can be connected to medical robots.

Belazzoug et al. (2020) proposed a new enhanced SCA for solving the feature selection problem (ISCA), which allows for better search in the search space. It is dissimilar to the basic SCA which focuses only on the best-obtained solution to produce a new solution. To validate the proposed ISCA method, a series of experiments on 9 text collections is carried out. The results showed the proposed ISCA got a high performance compared with other similar methods, which means it is a useful method for text categorization problems. Rahimi (2019) proposed a new method that uses only data of one index for foretelling in most forecast rules, but employs a two-stage system of multi-layer perceptron NN. In this method, several criteria are utilized to forecast with SCA to select the most suitable samples after NN training. The results showed that the proposed method can achieve a lower forecast error compared with other similar methods.

4.5 Networks applications

Ismael et al. (2017) proposed a method using SCA for choosing the optimal choice of leaders in radial configuration networks. The proposed method is employed to a real Egyptian configuration system. The results showed that the proposed method got effective performance in overcoming the network losses while keeping the particularized restrictions over ten years and taking into account high yearly load increase rates. Majhi (2018) proposed a method for solving breast cancer analysis utilizing a supply preface NN trained by the SCA, SCA-NN. The advantage of the SCA-NN is confirmed by testing on the Wisconsin Hospital dataset and matching with other similar results. The results showed that the proposed SCA-NN is very strong, effective, and obtains more correct analyses compared to other similar methods.

Pandey et al. (2018) proposed a method that uses SCA in routing and clustering for improving the working life of WSNs. The cluster head (CH) in the arrangements requires more power expense so some more expensive power connections are utilized to achieve CHs operations for an improvement of its lifetime. The results showed the ability of the proposed method at various locations. Raut and Mishra (2019) proposed an improved method using SCA for addressing the problem of the power distribution network reconfiguration (PDNR). To keep stability between local and global search, four random values (r1, r2, r3, and r4) are combined into the proposed method. The performance of the proposed method is examined by analyzing 5 test distribution arrangements (33, 69, 84, 119, and 136 buses). The results showed the superiority of the proposed method.

4.6 Parameters setting

Li et al. (2018) proposed a new method using support vector regression to solve time series prediction problems, called SCA-SVR. In the proposed SCA-SVR, the SCA is used for parameter tuning of SVR. The proposed SCA-SVR method is compared to other similar methods. Benchmarks are chosen to include a range of potential practical cases. The proposed SCA-SVR method proved to be achievable efficiently and probably. Aydin et al. (2019) proposed a comparative study to examine the parameters of PV-cell using Whale Optimization Algorithm (WOA) with SCA and compared it with other similar methods. These parameters are also essential for energy and maximum energy tracking. The results showed the ability of the proposed method in solving this problem. Singh (2017) proposed a new method to solve parameters setting. They proposed a novel approach for loss of higher-order constant systems using SCA. The main benefit of the proposed method is that it always produces a stable reduced-order model for the stable higher-order continuous system. The proposed method outperformed other similar methods.

4.7 Scheduling applications

Das et al. (2018) proposed a new method using the SCA to solve the problem of short-term hydrothermal scheduling. Hydrothermal scheduling is recognized as an optimization problem by expressing objective functions using various equality and difference restrictions. The results achieved by the proposed SCA are compared with other similar methods, and it is recognized that it produces superior results. Utama (2019) proposed a new hybrid method, hybridization SCA with Flow Shop Sequence Dependent Setup (FSSDS), to solve the carbon emissions problem, called HSCA. Several experiments are conducted to examine the parameters and effectiveness of the proposed method. The result showed that the proposed HSCA got better performance compared to other similar methods. Abdelsalam and Mansour (2019) proposed a new hybrid method to solve the problem of optimal allocation and hourly scheduling of capacitor banks (C-Bs) using DCS in order to reduce the cost-saving and improve the system safety. The results showed the superiority of the proposed method by comparing its results with other similar methods.

5 Results and comparisons

This section presents a wide range of benchmark test problems with different characteristics [as shown in Table 3) to investigate, analyze, and confirm the effectiveness of the SCA (Mirjalili 2016) compared to other similar optimization algorithms (i.e., Particle Swarm Optimization (PSO) (Eberhart and Kennedy 1995), Generic Algorithm (GA) (Koza 1992), Bat Algorithm (BA) (Yang 2010b), Firefly Algorithm (FA) (Yang 2010a), and Gravitational Search Algorithm (GSA) (Rashedi et al. 2009)]. Results values are normalized between 0 and 1 to analyze and compare the results of all benchmark functions. To conclude the significance of the obtained results, a ranking statistical test called Friedman ranking test is conducted and is shown in Table 4.

As shown in Table 3, the obtained results show that the SCA got better results in almost all test cases. Firstly, the SCA gives better results on three out of six unimodal benchmark functions. Because of the properties of the unimodal test functions, these obtained results confirmed that the SCA has high exploitation search and convergence rates. Secondly, as shown in Table 3, the results confirmed that the SCA got better results compared with all optimization algorithms employed on the multi-modal benchmark functions (F7, F9, F11, and F12). The obtained results confirmed the SCA benefits from high exploration search

Table 3 The average results for solving benchmark functions

Function	Comparative algorithms					
	PSO	GA	BA	FA	GSA	SCA
F1	0.0003	0.8078	1.0000	0.0004	0.0000	0.0000
F2	0.0693	0.5406	1.0000	0.0177	0.0100	0.0000
F3	0.0157	0.5323	1.0000	0.0000	0.0016	0.0371
F4	0.0936	0.8837	1.0000	0.0000	0.1177	0.0956
F5	0.0000	0.6677	1.0000	0.0000	0.0000	0.0005
F6	0.0004	0.7618	1.0000	0.0000	0.0000	0.0002
F7	0.0398	0.5080	1.0000	0.0009	0.0021	0.0000
F8	1.0000	1.0000	0.0000	1.0000	1.0000	1.0000
F9	0.3582	1.0000	0.4248	0.0190	0.0222	0.0000
F10	0.1045	0.8323	0.8205	0.0000	0.1569	0.3804
F11	0.0521	0.7679	1.0000	0.0074	0.4011	0.0000
F12	0.0000	0.4573	1.0000	0.0000	0.0000	0.0000
F13	0.0000	0.6554	1.0000	0.0000	0.0000	0.0000
F14	0.1816	0.4201	1.0000	0.0000	0.0961	0.3908
F15	0.3016	0.0000	1.0000	0.4395	0.2926	0.0230
F16	0.0427	0.0000	0.3572	0.5298	1.0000	0.0497
F17	0.0294	0.1093	0.8189	0.7093	0.7887	0.0000
F18	0.1772	0.0000	1.0000	0.0723	0.8018	0.0129
F19	0.7727	0.0192	1.0000	0.8176	0.9950	0.0000
Sum	3.2346	9.9634	16.421	3.6134	5.6858	1.9911

Table 4 The results of the Friedman ranking test

Function	Comparative algorithms					
	PSO	GA	BA	FA	GSA	SCA
F1	3	5	6	4	1	1
F2	4	5	6	3	2	1
F3	3	5	6	1	2	4
F4	2	5	6	1	4	3
F5	1	5	6	1	1	4
F6	4	5	6	1	1	3
F7	4	5	6	2	3	1
F8	2	2	1	2	2	2
F9	4	6	5	2	3	1
F10	2	6	5	1	3	4
F11	3	5	6	2	4	1
F12	1	5	6	1	1	1
F13	1	5	6	1	1	1
F14	3	5	6	1	2	4
F15	4	1	6	5	3	2
F16	2	1	4	5	6	3
F17	2	3	6	4	5	1
F18	4	1	6	3	5	2
F19	3	2	6	4	5	1
Summation	52	77	111	44	54	40
Average	2.73	4.05	5.84	2.31	2.84	2.10
Final ranking	3	5	6	2	4	**1**

and avert from the trapped in local optima. Finally, the results of the SCA on the composite benchmark functions confirmed the excellence of SCA in solving optimization problems with extended search spaces. According to the normalization results, the overall performance of all comparative algorithms can be compared also. The last row of Table 3 shows the summation of the average results of all algorithms on all benchmark functions. It is observed that SCA gives the minimum average value that SCA reliably overwhelms other comparative algorithms. Table 4 shows the summation, average, and final ranking of the ranking results of all algorithms on all benchmark functions. The ranking results in Table 4 show that performance of the SCA is statistically significant; it got the first ranking compared with all comparative algorithms followed by FA, PSO, GSA, GA, and BA.

6 Discussion

This section explains the theoretical aspects, assessment, and evaluation of SCA.

6.1 Theoretical aspects

Global optimization problems like numerical benchmark functions are linked to a process of obtaining optimal solutions of a numerical system by determining the minimum or maximum of the given objective function. Due to the enhanced complexity of optimization functions employed in several real-world problems, the development of powerful optimization techniques is becoming more valuable, critical, and important than previously. Over the earlier decades, various optimization techniques have been applied according to several characters of biology or nature-life.

Generally, as mentioned before the Introduction section, optimization algorithms are divided into two sub-classes of individual optimization algorithms (works with one randomly generated solution) and population optimization algorithms (works with a set of randomly generated solutions). Large gradient data is needed by the individual optimization algorithms; usually, it goes with one single solution and improves overhead using a predefined number of iterations. The less mathematical computation is required by these kinds of optimization algorithms and a good procedure is performed to achieve the optimal global solution for easy patterns or problems. But they usually have defects such as inference mechanisms, quick convergence, and unstable search in complex problems. Regarding the latter, the optimization processes have a tendency to start with a population of initial random solutions, produced within the available search space and evolved repetitively. It would be very powerful and helpful to employ this kind of optimization technique to prevent being trapped in local optima. Also, the mutual information among the competitor solutions helps the handled algorithm to improve its solutions over various difficulties of complex-wide search spaces (Gharehchopogh and Gholizadeh 2019).

Searching methods are classified into two milestones, which is the main influence of population methods [i.e., stochastic search methods: exploration search (i.e., diversification/globally) and exploitation search (intensification/locally)] (Malhotra et al. 2017). The above-mentioned (exploration search) denotes how the population solutions have a tendency to be improved iteratively and examine the promising regions of the search area as far as possible. In contrast, the search solutions are established by the exploitation method to converge close to the near-optimal solution obtained in that stage.

The focusing on exploitation search has resulted in a quick convergence, but powerful local search avoidance is the result of keeping a variety of solutions. Consequently, a conventional procedure should run to provide a better balance among these search methods. New meta-heuristic optimization methods have been employed successfully in tackling a wide range of real-world problems because of their features: flexibility, simplicity, privation-free mechanisms, and the ability to avoid the local optima. That is why these methods (i.e., population-based algorithms) have been applied to solve different areas effectively. Scholars have implemented many strong, successful, and helpful optimization methods motivated by nature-life.

The advantage of meta-heuristics is delineated for several reasons. The first reason is that the utility of the stochastic system supports meta-heuristics to stay away from being stuck in local optima and to converge to the near-optimal solution. The aim here is not to obtain the exact best solution but to obtain a near-optimal solution within a sensible computational time. The main factor to give such a result depends on the conventional balance between the search strategies (exploration and exploitation). Exploration's aim is to discover the encouraging spaces in a complex-wide search space by the exploration of search areas effectively. Consequently, the exploitation search is intensified by the exploration strategy in a promising area to find high-quality solutions. Better achievement and performance of a particular meta-heuristic algorithm is a trade-off between these two approaches; better performance will be accomplished. The current optimization algorithms adjust the balance between these two methods in several ways. They could be further adjusted by modifying it for better exploration or better exploitation searches. Two or more algorithms' components linked by hybrid meta-heuristics may take advantage of the power of each, all while avoiding as much as possible their problems and drawbacks. Moreover, the success of meta-heuristic algorithms is due to their principle, intelligence, ease of use, and fit in practice.

As mentioned before, hybridizing meta-heuristics by combining its components together wins the advantages of their components. It can be performed between different optimization techniques in different levels including the development of intrusion within both parts of the algorithms (i.e., high-level hybridization proves that low intrusion among the internal operations of optimization algorithms, and low-level hybridization means that just a meta-heuristic design is given to another). Through the optimization procedures, the hybrid meta-heuristic algorithms may augment information by combining more than one operator to produce a powerful search method. Additionally, the execution sequences of the algorithms procedures must be taken into account.

Swarm intelligence techniques, in an abstract definition, are commonly known as meta-heuristic optimization algorithms. Meta-heuristics are high-level stochastic search techniques that lead and draw the search operators to iteratively renew the candidate solutions to enhance it. Usually, the solution is consequently developed (therefore optimized) by corresponding to some random possibilities and elements, in the purpose of gaining an excellent solution in terms of the solution nature, while the achieved solutions are obtained from one random (stochastic) iteration to the following iteration. In opposition to inevitable rules, meta-heuristics may not be completely perfect to get the best solution to tackle an optimization problem as it has been introduced. Usually, they effectively produce a satisfactory solution (near-optimal solution) in most cases within a satisfactory computational time (an equitable running time).

Meta-heuristic algorithms have been extensively applied to tackle different optimization problems. But for sophisticated (complex) problems or real-life situations, most algorithms still suffer from being trapped in local optimum and they fail to produce the near-global optimum. This is the reason for the exploration (diversification or global search) focus (i.e., component) inside the handled algorithm. Several exploration methods are operated to increase the performance of well-known optimization algorithms and support in preventing the drawbacks. These methods are modifying, hybridization, and elitism: the presence of elite operators as a masterful dominating element in a method (Rakshit et al. 2017; Gotmare et al. 2017).

SCA has employed to solve different problems exponentially and become a powerful search technique for solving complex optimization problems. It is an intelligent algorithm, and it runs by stochastic computational mechanisms that are used to find the near-optimal solution for the one-dimensional/multi-dimensional functions based on the minimum/maximum objective functions. The SCA has a simple procedure, which can be easily performed and simply applied in several domains. The results summarized in this paper provide strong evidence and proof of the performance accomplishments of the SCA in terms of production (performance) and quality of the best-obtained solution. This declaration is concluded based on studying and analyzing the obtained results of comparisons among the SCA and other similar published algorithms.

Similar to any optimization algorithm, SCA has both benefits (strong features and advantages) and some determined shortcomings (weaknesses and disadvantages). Although there is no convergence evidence for this algorithm, the results reviewed in this paper demonstrate that the SCA competes effectively across other optimization algorithms in the values of convergence. Table 5 shows the strong points (advantages) and weak points (disadvantages) of SCA. It has several advantages, such as combining with other

Table 5 Advantages and disadvantages of the Sine Cosine Algorithm

Advantages	Disadvantages
Combining with other algorithms is strangely satisfying	The first version of SCA has been proposed for continuous optimization problems
A good convergence velocity	Suffer from premature (earlier) convergence
The accelerated manner in getting excellent solutions	No theoretical converging nature
Proper for many kinds of hard optimization problems	Probability configuration changes by generations
An effective global method to search	Four parameter tuning
Proper for extended search space (i.e., continuous and discrete)	
Powerful neighborhood search features	
Flexibility, robustness, and adaptivity are discovered as important characteristics	
Strong in managing an extended number of decisions	
Higher probability and performance in getting global optima	
Lower reasonable likelihood of being trapped in a local optimum	
Less dependence on initial random solutions	
SCA is easily in its design and implementation connected to other optimization procedures	
Reduced execution time	

algorithms is surprisingly satisfying, a good convergence velocity, powerful neighborhood search features, and a robust global method to search which enables the algorithm to solve the different problems effectively. However, it is suffering from some drawbacks such as premature (earlier) convergence, no theoretical convergence nature, and probability configuration changes by generations. These drawbacks need further investigations, which open the direction for future researchers.

Reviews on meta-heuristic-based optimization algorithms from earlier years reveal some confusion. Typically, they emphasize various performance functions such as the algorithm's sensitivity (skills, expertise, ingenuity, and such) of the scholars in algorithmically-constructed tuning. To reach the maximum performance of any optimization algorithm, parameters' fine-tuning would be useful and needed. The change in the achieved results of any algorithm presents at least two primary drawbacks: (I) From one side, the problem of reproducibility of results arises, given such solutions as implementation activities, a special method of data combinations, and experience in parameter modification. It is well-known information that any algorithm implemented by two different scholars can produce totally different results. This is because the work of comparing, matching, and completely evaluating any optimization algorithm and its performance is challenging and can be improved. (II) From the other side, it is forecasted that a problem of performance maximization occurs: one of the commonalities of substantially all introduced optimization criteria is that they are characterized by a predefined number of tuning parameters whose value(s) fully affect the overall effectiveness of any optimization algorithm itself. It is a common understanding that fine-tuning parameters of any algorithms are not only dilemma-qualitative, but are also demand-qualitative. Also, for any optimization problem, it is expected that these parameter values should be fine-tuned (can be changing) to suit a

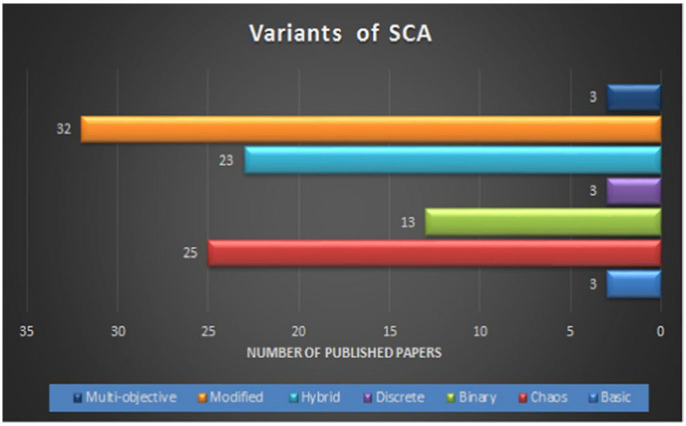


Fig. 4 Variants of the Sine Cosine Algorithm

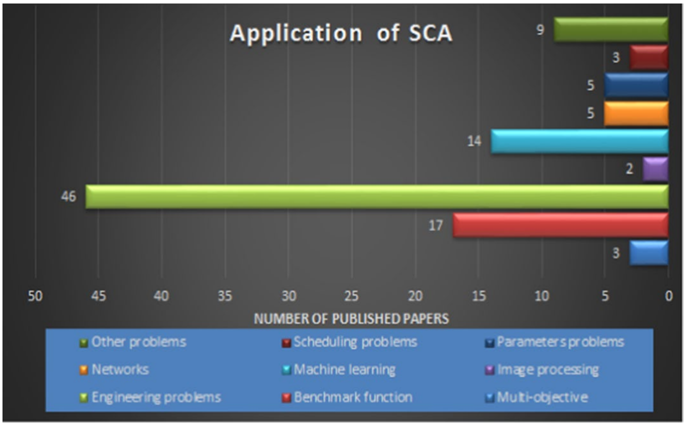


Fig. 5 Applications of the Sine Cosine Algorithm

particular task based on its case-specific information (e.g., the arrangement of its values, how difficult the problem is, case size, etc.).

One of the main difficulties linked to SCA is how to manage the probabilistic convergence properties of SCA, which is required to fully understand the presented algorithm. The problem of quick convergence (premature convergence) in the SCA usually leads the search processes to be stuck in the local optimum. Usually, this problem occurs when the solutions' heterogeneity losses and the solutions cannot avert the falling in the local optima. Furthermore, there are high potentials for scholars to use and employ the advantages of SCA to tackle complex industry and real-world problems.

Figure 4 presents a summary of publications based on the classes of SCA variants. As well, Fig. 5 presents a summary of publications based on the classes of SCA applications. Finally, Fig. 6 presents numbers of published papers (i.e., journals, conferences, and chapters), which are classified based on the publisher and years. Based on the literature given, there are trending issues from the years 2016 to 2019. Figure 6 presents various kinds of

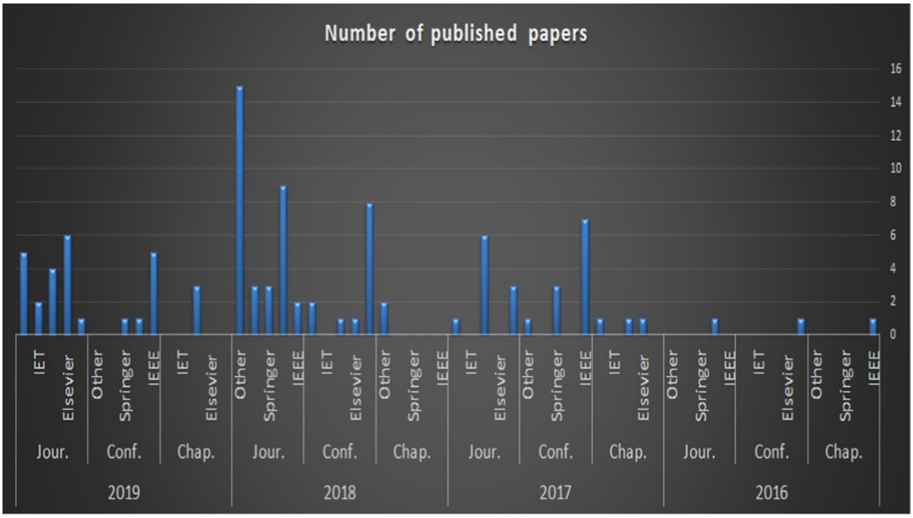


Fig. 6 Number of publications of the Sine Cosine Algorithm per year

hybridization (improved, basic, binary, variants) and their applications in regards to the total number of papers published each year. As observed in this figure, 2018 and 2019 show the highest utilizing of SCA compared to the remaining years. This certainly demonstrates that the use of the SCA in the optimization field has gained exponential interest after its first year of introduction. Figures 4 and 5 demonstrate clearly that the SCA was successfully employed to different optimization problems.

6.2 Assessment and evaluation of Sine Cosine Algorithm

As evaluated and reviewed before, the SCA has been successfully used to address several different complicated optimization problems since it was launched. The motivation, four parameters need to be tuned, and adaptive exploratory operation are the foremost important purposes for the success of this optimization algorithm (SCA). These purposes will be beneficial for future scholars to conduct research in that area. In comparison with other introduced algorithms in the literature, however, it has some shortcomings, limitations, and certain disadvantages.

The main limitations that have been addressed with this kind of method derive from the NFL theorem ("No free lunch" theorem in search and optimization area). In other words, this theorem says no fit algorithm can tackle various kinds of optimization problems efficiently. The effectiveness (performance) of all classes of algorithms met over a standard limited set (F) of benchmark test functions which are similar iff (if and only if) F is produced under change. It means that SCA needs modification, hybridization, adjustment, and changing (modeling) when solving real-world problems. A different limitation is the objective function (i.e., single-objective function) of this optimization algorithm: it is qualified to tackle just the classes of single-objective problems. Other classes of the objective function (i.e., multi-objective function) of this optimization algorithm make it able to tackle just the classes of the multi-objective optimization problems. The objective function should be presented with special mechanisms to tackle any class of optimization problems such as binary, dynamic, multi-objective, discrete, continuous, and other.

The drawback of the SCA is the low ability to handle the complexities of multi-modal search problems. Adding a random sophisticated operator to develop the solutions through the optimization operations will enhance the opportunity and likelihood of finding the near-optimum solution in tackling the multi-modal problems. The performance of the SCA increases associated with the number of variables' decisions. This is feasible because of the diversity of the initial solutions is increased when tackling such problems, and sine and cosine cannot avert getting stuck in the local optima. Meanwhile, there is no specific idea or operation to solve the problem of local optima in the literature. This gives scholars in this area several opportunities to conduct research.

The scholars of the SCA performed sufficient experiments and investigated several collections of results in the average performance using standard benchmark problems and using a set of real-world problems. Despite this work, more examination groups are expected to tackle medium/large computation problems. Moreover, the fast convergence speed/rate and weak local search to explore local optimum should be considered when tackling difficult problems with a big number of variables or decisions. Mechanisms such as search methods should be designed to overcome the convergence problem and exploitation rules if the algorithm is trapped in local search. Adaptive new search methods are considered as useful agents in this regard to enhance the acceleration of the convergence corresponding to the number of algorithm iterations.

7 Conclusion and possible future directions

In this survey, we have seen that the SCA has been successfully applied to optimization problems that arise in many fields, including machine learning, image processing, software engineering, networking, and others. Future research directions could include new applications, including multi-objective and discrete optimization problems, and hybridizing the SCA with other algorithm components such as differential evolution or hill climbing.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest

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