Neural Computing and Applications (2020) 32:11195–11215
https://doi.org/10.1007/s00521-019-04629-4

REVIEW ARTICLE

Salp swarm algorithm: a comprehensive survey

Laith Abualigah[1] · Mohammad Shehab[2] · Mohammad Alshinwan[1] · Hamzeh Alabool[3]

Received: 25 March 2019 / Accepted: 22 November 2019 / Published online: 29 November 2019

Abstract
This paper completely introduces an exhaustive and a comprehensive review of the so-called salp swarm algorithm (SSA) and discussions its main characteristics. SSA is one of the efficient recent meta-heuristic optimization algorithms, where it has been successfully utilized in a wide range of optimization problems in different fields, such as machine learning, engineering design, wireless networking, image processing, and power energy. This review shows the available literature on SSA, including its variants, like binary, modifications and multi-objective. Followed by its applications, assessment and evaluation, and finally the conclusions, which focus on the current works on SSA, suggest possible future research directions.

Keywords Salp swarm algorithm · Meta-heuristic optimization algorithms · Optimization problems · Bio-inspired algorithms

1 Introduction

Optimization technique has been established in many different domains, such as data mining, engineering applications, energy, networks, economics and medical. It is mainly employed to find several optimal decision or value to generate a candidate solution that can solve the problem effectively. Generally, optimization problems are working under considering the minimization or maximization of a potential decision-that making an algorithm normally adapted. The main purpose of decision making is to determine the optimal value of several available alternatives. The final result of optimization processes is the choice of the best decision or value from all given options. Best word refers to a satisfactory solution, which is the best option to solve the given optimization problem. Moreover, the achievable better solution over a series of processes may be estimated as a satisfactory solution [1, 2].

Recently, researches in optimization fields have survived active and got promising results due to its real close to all problems (i.e., industry-type problems, mathematical problems, real-world problems, and other problems) that belong to the category of hard optimization problems called NP-hard in nature [3–6]. Usually, the main aim of using the optimization techniques is to find the best decisions (problem solutions) by optimizing its objective function or fitness function. Optimization problems are divided into four main categories: first, constrained or unconstrained, sound, continuous or discrete, third, single- or multi-objective, and fourth, static or dynamic. In recent decades, because of the tincture challenges of these problems, several nature-inspired optimization algorithms have been proposed in the literature to tackle various types of optimization problems. The saleability of these algorithms in solving the problems is attractive because of their powerful and robust searchability and its procedures in tackling the high-dimensional problems better enough than other methods (i.e., calculus-based methods). Normally,

✉ Laith Abualigah
lx.89@yahoo.com; laythdyabat@aau.edu.jo

Mohammad Shehab
moh.shehab12@gmail.com

Mohammad Alshinwan
mohmdsh@aau.edu.jo

Hamzeh Alabool
h.boul@aau.edu.jo

[1] Faculty of Computer Sciences and Informatics, Amman Arab University, Amman, Jordan

[2] Department of Computer Science, Aqaba University of Technology, Aqaba, Jordan

[3] College of Computing and Informatics, Saudi Electronic University, Abha, Saudi Arabia

optimization algorithms are developed based on studying the natural phenomena of life when some species or living organisms are seeking for a better life. The general categories of these algorithms, as shown in Fig. 1, are (1) local search-based algorithms, (2) evolutionary search-based algorithms, and (3) swarm search-based algorithm.

The first category, the local search-based algorithms, works with a single passing solution, which will be iteratively developed (increase its fitness function) until the termination criteria are reached. Examples include simulated annealing [7], *B*-hill climbing [8], tabu search [9], and hill climbing [10]. The second category, the evolutionary search-based algorithms, works with a population strategy (collection of randomly generated solutions), which iteratively mix the solutions, until the acceptable solution (optimal) is reached, in order to get new and better solutions in terms of its fitness function. Examples include genetic algorithm [4], genetic programming [11], cuckoo optimization algorithm [12], firefly algorithm [13], ant colony optimization [14], and harmony search algorithm [15]. Finally, the last category, the swarm search-based algorithm, works with a population-based technique, and at each iteration, the current solutions are normally produced based on historical information obtained by prior generations. Several algorithms in this section are bat algorithm [16], Krill herd algorithm [17], symbiotic organisms search algorithm [18], dragonfly algorithm [19], cuckoo search algorithm [20], artificial bee colony algorithm [21], flower pollination algorithm [22], moth-flame optimization algorithm [23], bacterial foraging algorithm [24], biogeography-based optimization [25], gray wolf optimizer (GWO) algorithm [26], ant lion optimization [27], particle swarm optimization algorithm [28], spotted hyena optimizer algorithm [29], and other related studies found in [1, 17] (see Fig. 1, which shows the common diagram for optimization algorithms).

Swarms (groups) of the pelagic tunicate form through the spring, and the problems of the large intersexual variability in the volume of salp groups are unclear and occult. Differences in asexual reproduction of *T*. democratic populations (community) in the tidal waters of southeast Australia direction (32–35 S) were recognized in three austral springs (October 2008–2010). *T*. democratic abundance was much higher in 2008 (1312 individuals $m-3$) than 2009 and 2010 (210 and 92 individuals $m-3$, respectively). There was a important negative roles (linear regression, $r_2 = 0.61$, $F1.22 = 33.83$, $P < 0.001$) between abundance and asexual generation. Thus, corresponding growth rates decreased with decreasing abundance. Generalized additive combined modeling revealed that *T*. democratic abundance was positively associated with the preferred food $2 >$ µm in size ($P < 0.05$) and negatively associated with the proportion of non-salp zooplankton ($P < 0.001$). Salp swarm size, growth, and asexual generation may depend on the abundance of massive phytoplankton (bacteria) and contest with other zooplankton [30].

The main aim of this review paper is to conduct a comprehensive study of all perspectives of SSA in computer science domain, and how the researchers in that domain are excited and motivated to implement it in different applications to solve different problems. Moreover, this review paper highlighted and call attention to the

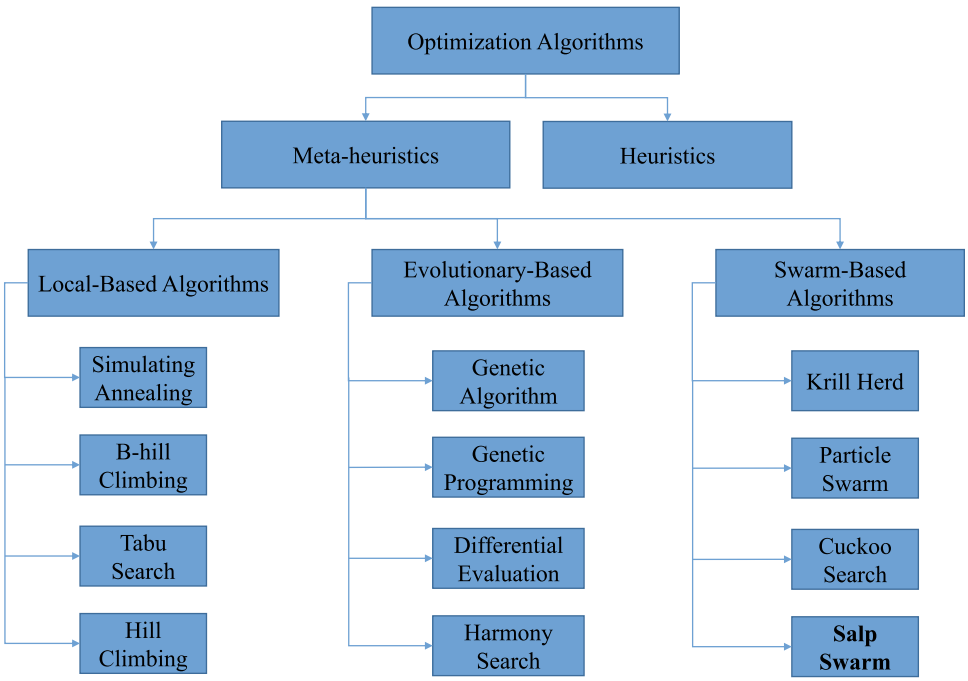

Fig. 1 Optimization algorithms

robustness of the SSA and the alterations suggested in the literature to overwhelm the algorithm weaknesses. Besides, the review referred to all of the past research that examined the SSA by leading to the different well-regarded publishers (i.e., Springer, Elsevier, IEEE, Taylor and Francis, Hindawi, Inderscience, and other publishers). Figure 2 shows the number of publications (i.e., journal papers, conference paper, chapter books, and others), which are classified based on the publisher of the SSA publications. Figure 3 shows the classified of these publications based on the class of application (problem).

This review discusses and presents the SSA based on two main classifications:

- Theoretical aspects of SSA includes the SSA versions of binary, modifications, hybridizations, chaotic, multi-objective, and parameter-less. Figure 3 shows the classification of the theoretical viewpoints of SSA based on the classes of alterations.
- Applications of SSA involve machine learning applications, engineering applications, image processing, wireless networking, and other SSA applications. Figure 2 shows the number of publications, which are classified based on the classes of applications.

This rest of this paper is organized as follows: The main procedures of the SSA and its organization are shown in Sect. 2. In Sect. 3, the theoretical aspects of SSA and development details are reported. In Sect. 4, applications of SSA are outlined and highlighted. Assessment and evaluation of SSA are shown in Sect. 5. Finally, in Sect. 6, the conclusion, future works, and possible research directions of SSA are provided.

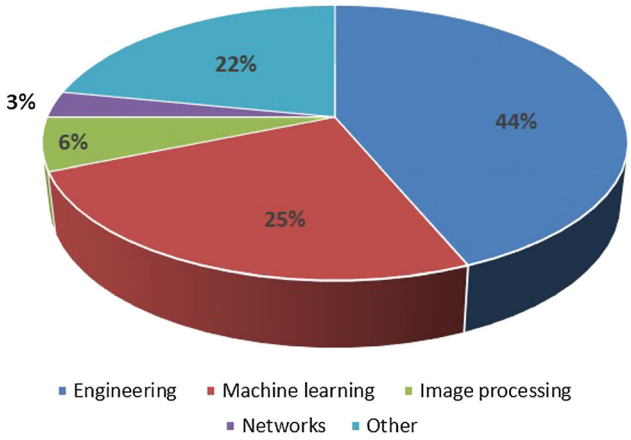

Fig. 3 SSA applications

2 Salp swarm algorithm

This section presents the SSA and describes its main elements. It also includes explanations on the convergence, exploitation, and exploration of this algorithm.

2.1 Inspiration of SSA

Over 1.2 million species of marine organisms already cataloged in a central database [31]. Most of these species have the same behaviors and features, such as communicating methods, locomotor performance, and looking for food. Salp is a kind of marine organism which belongs to the family of Salpidae. Its shape is highly similar to jellyfishes, cylindrical shape with openings at the end which pump water through their gelatinous bodies to move and

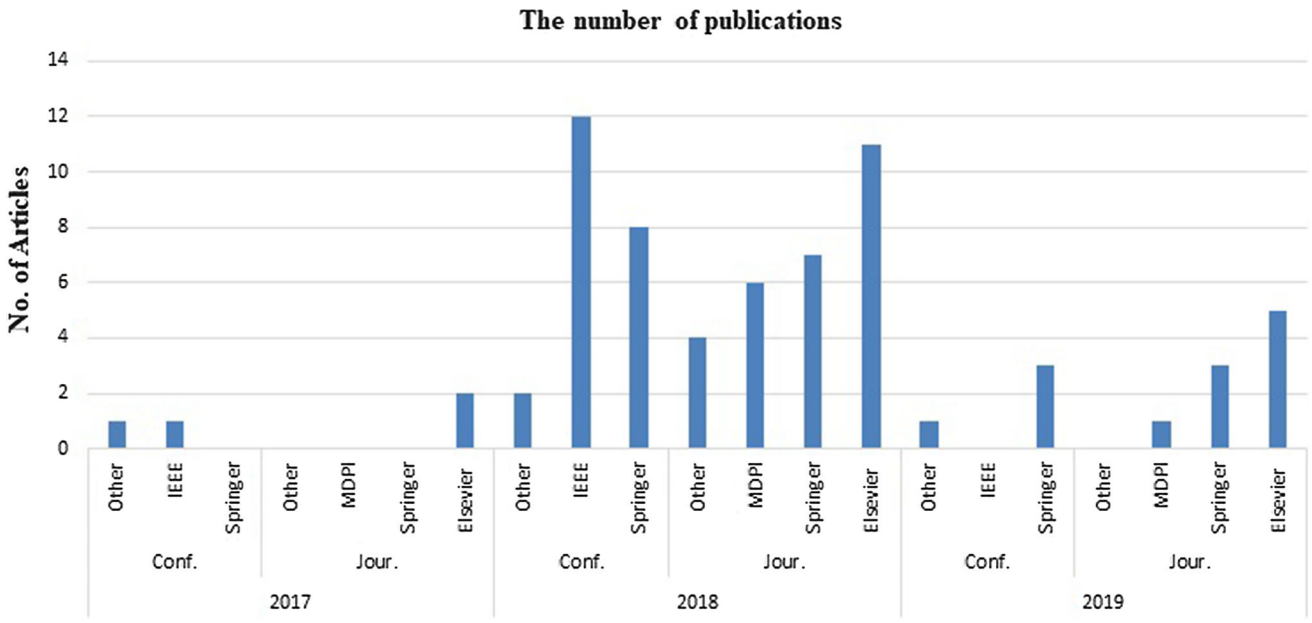

Fig. 2 Number of publications of SSA per publisher

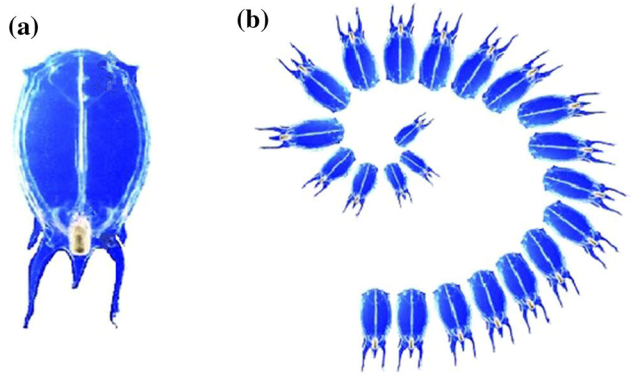

Fig. 4 **a** Individual salp, **b** swarm of salps (salp chain)

feed by internal feeding filters. Figure 4a shows the shape of a salp.

As mentioned above, the marine organisms share some behavior such as swarming behavior. For example, for fish, it is called the school of fish [32], while for salps it is called salp chain (see Fig. 4b). Although their living environments are extremely difficult to access, the biological researchers believe that this behavior helps the salps for achieving better locomotion and foraging.

2.2 The procedure of basic salp swarm algorithm

Salp swarm algorithm (SSA) is a population-based optimization method proposed by Mirjalili et al. [33]. The behavior of the SSA can be convincible by computing it with the salp chain searching for optimal food sources (i.e., the target of this swarm is a food source in the search space called **F**). In SSA, according to the individuals' (i.e., salps) positions in the chain, they are divided into either leaders or followers. The chain is started with a leader and the followers follow it to guide them in their movements. Figure 5 shows the main steps of the SSA's flowchart, followed by more details about its procedures.

Algorithm 1 shows the pseudocode of SSA, where the simplicity of SSA and the its similarity to other swarm intelligent algorithms can be noted. Where it starts by initializing the salp population, the swarm X of n salps is represented in Eq. 1 as two-dimensional matrix. Then the fitness of each salp is calculated to determine the salp with the best fitness (i.e., leader). The leader position is updated using Eq. 2

$$X_i = \begin{bmatrix} x_1^1 & x_2^1 & \dots & x_d^1 \\ x_1^2 & x_2^2 & \dots & x_d^2 \\ \vdots & \vdots & \dots & \\ x_1^n & x_2^n & \dots & x_d^n \end{bmatrix} \tag{1}$$

$$x_i^1 = \begin{cases} y_i + r_1((\mathrm{ub}_i - \mathrm{lb}_i)r_2 + \mathrm{lb}_i) & r_3 \geq 0 \\ y_i + r_1((\mathrm{ub}_i - \mathrm{lb}_i)r_2 + \mathrm{lb}_i) & r_3 < 0 \end{cases} \tag{2}$$

where the x_i^1 is the position of the first salp in the ith dimension and y_i is the food position in the ith dimension. lb_i and ub_i represent the lower bound and the upper bound of the ith dimension, respectively, and the coefficient r_1 is calculated by Eq. 3. r_2 and r_3 are random numbers between [0,1].

$$r_1 = 2\mathrm{e}^{-\left(\frac{4l}{L}\right)^2} \tag{3}$$

where L is the maximum iterations and l is the current iteration. It is worth mentioning that the coefficient r_1 is very important in SSA because it balances exploration and exploitation during the entire search process. Regarding the followers, Eq. 4 shows the update of their positions:

$$x_i^j = \frac{1}{2}\lambda t^2 + \delta_0 t \tag{4}$$

where $j \geq 2$, x_i^j refers to the position of the jth salp in the ith dimension, δ_0 is an initial speed, t is the time, and $\lambda = \frac{\delta_{\mathrm{final}}}{\delta_0}$, where $\delta = \frac{x - x_0}{t}$. In optimization, the time indicates the iteration. So, the discrepancy between iterations is equal to 1. Considering the assumption that $\delta_0 = 0$, the following equation is employed for this issue.

$$x_i^j = \frac{1}{2}\left(x_i^j + x_i^{j-1}\right) \tag{5}$$

where $j \geq 2$. In case some salps move outside of the search space, Eq. 6 illustrates how to bring them back to the search space.

$$x_i^j = \begin{cases} l^j & \text{if } x_i^j \leq l^j \\ u^j & \text{if } x_i^j \geq u^j \\ x_i^j & \text{otherwise} \end{cases}. \tag{6}$$

Algorithm 1 The Procedure of the Salp Swarm Algorithm

```
Require: Initialize the salp population x_i (i = 1, 2, ..., n) consider ub and lb.
while (End condition is not satisfied) do
    Calculate the fitness of each search salp
    F=the best search solution
    Update r1 by Eq.(3)
    for (each salp (x_i)) do
        if (i==1) then
            Update the position of the leading salp by Eq.(2)
        else
            Update the position of the followers salp by Eq.(5)
        end if
    end for
    Verify the position of salps based on the upper and lower bounds
end while
return F
```

2.3 Exploration and exploitation in SSA

Few couples of words, such as exploration and exploitation, global search and local search, and diversification and

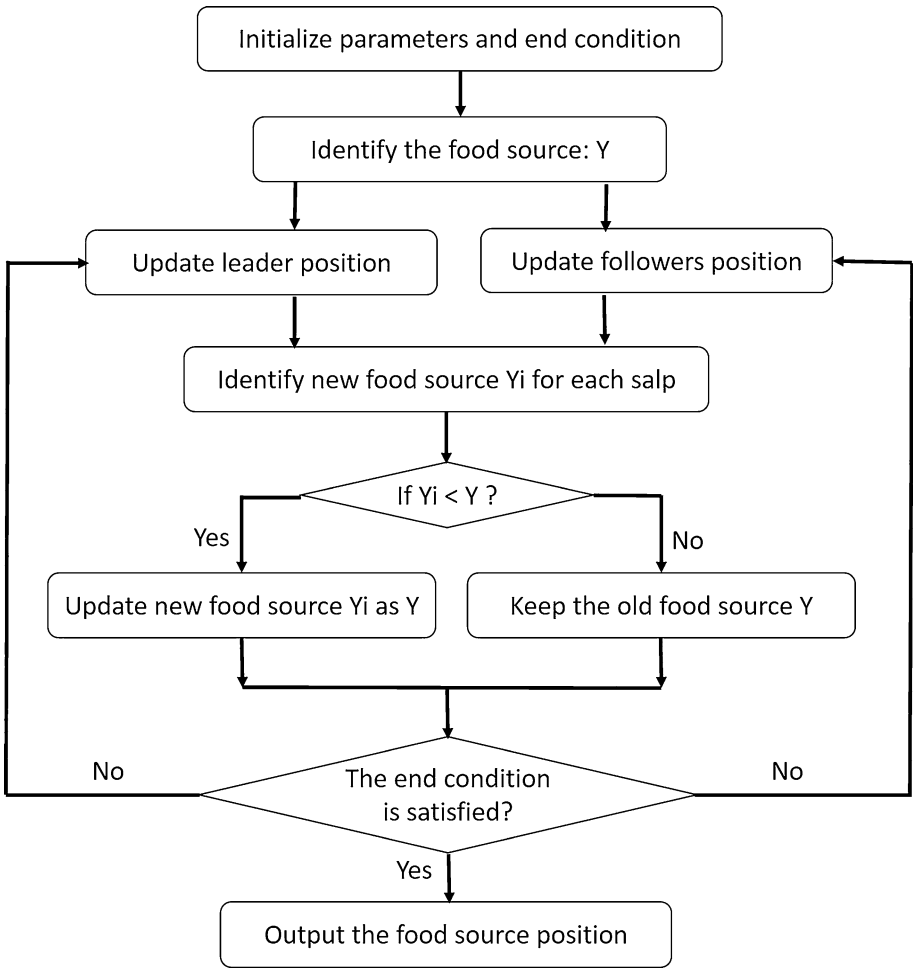

Fig. 5 Flowchart of the salp swarm algorithm [34]

intensification [35], are very common in the optimization algorithms, where all algorithms do contain at least one of these pairs [36]. In general, the exploration aims to discover the promising areas of the search landscape, prevent solutions from stagnating in a local optimum, and maximize the probability of detecting the global optimum. The exploitation aims to obtain even better solutions from good ones through discovering the neighborhood of each solution [37].

In SSA, the responsible parameter of balance between exploration and exploitation is called coefficient r_1 which has been calculated using Eq. 3. However, SSA suffers from a problem in exploitation which leads to the slow convergence rate [38, 39].

Similar to various optimization techniques, SSA holds some benefits (strong points) and few disadvantages (weaknesses). Even though there is no confluence evidence for this optimizer, the final features are summarized in this review to confirm the DA competitiveness over other optimization algorithms in regard to convergence stimulated (rate). Table 1 shows the strength (advantages) and weaknesses (disadvantages) of DA.

3 Variants of salp swarm algorithm

The SSA proposed in 2017, it is a recent optimization algorithm in comparison with the Krill herd algorithm, firefly algorithm, harmony search algorithm, particle swarm optimization algorithm, and ant colony algorithm introduced in 2012, 2008, 2001, 1995, and 1992, respectively. But, the SSA has been renewed for various modifications developed by researchers to face and solve wide range optimization problems. Most of these modifications will be extensively but not exhaustively illustrated. A brief summary of the main variants of SSA is reported in Table 2.

3.1 Binary salp swarm algorithm

A binary search space is recognized as a hypercube. The solutions of a binary optimization algorithm force to only transfer to nearer and more distant corners of the hypercube by flipping several numbers of bits. Consequently, for producing a binary version of SSA, some essential concepts such as position updating rule should be changed. In

Table 1 Advantages and disadvantages of SSA

Advantages
Mixing with other algorithms is strangely satisfying
A good convergence acceleration
Accelerated process in getting excellent solutions
Suitable for many kinds of optimization problems
An efficient global scheme to seek
Fitting for wide search space
Powerful neighborhood search characteristic
Adaptability, robustness, and scalability are important characteristics found
Strong in managing a wide number of determinations
Has higher feasibility and efficiency in producing global optima
Lower plainly of stuck in local optima
Less reliance on initial solutions
SSA is easy in its idea and implementation associated with other heuristic optimization procedures
Reasonable execution time
A few parameter tuning
Disadvantages
The first suggestion of SSA has been proposed for solving engineering design problems
Suffers from premature convergence
No theoretical converging frame
Probability distribution changes by generations

the basic SSA, solutions could run around the current search space due to having vectors of positions with a continuous real region. Hence, the notion of position updating can be easily performed for solutions adding velocities to positions using binary transfer equation. However, the purpose of position updating is changed in a binary space. In binary space, because of initializing with only two numbers ("0" and "1"), the position updating procedure cannot be done using the main equation of the positions updating in the basic SSA. Accordingly, there is a method can be used like sigma function to change solutions' positions from "0" to "1" or vice versa [40].

A novel work has been proposed in [41]. This work proposed a new version of SSA (binary) called BSSA based on modifying arctangent transformation to transform the continuous space into binary space. The proposed work has two characteristics concerning the transfer function and mobility. The authors worked to improve the exploration and exploitation capabilities of the SSA. The suggested approach tackles the optimization problems by comparing BSSA with other four variants of transfer functions; in addition, a comparative study with a different binary algorithm and twenty-four benchmark issues is conducted. The results show a superior performance of the modified BSSA variant compared with other variants.

In [42], the authors proposed two wrapper feature selection methods that used the SSA as a binary search strategy. In the first method, eight command functions are used to transform the continuous version of SSA to the binary version. In the second method, the crossover procedures are employed to replace the average operator to improve the investigation behavior of the algorithm. The proposed methods are tested on twenty-two UCI datasets, and the results are analyzed to compare with other five feature selection approaches [i.e., binary of gray wolf optimizer (BGWO), particle swarm optimization (BPSO), gravitational search algorithm (BGSA), bat algorithm (BBA), and genetic algorithm (GA)]. From the results, the proposed method notably outperformed other comparative methods on about 90% of the datasets.

A binary SSA is proposed in [43] with a new leadership structure and asynchronous updating rules. Many experiments are performed to discover the optimal number of leaders in the social development of the artificial salp chain. In the end, this improvement is developed to set the optimal leadership structure. Mimicked from the behavior of a termite swarm in breaking the termites into four classes, the salp chain is then split into several sub-chains, where the salps in each part (sub-chain) can trace a different approach to update their locations. Three other updating strategies are applied. This approach is tested and approved on twenty benchmark datasets. The results proved that using half of the salps as leaders of the chain better enhanced the performance of SSA according to the accuracy measure. Moreover, its single parameter is tuned dynamically to allow it to explore the search space effectively in dealing with various benchmark feature selection datasets.

Table 2 Summary of SSA variants

Variant	Name	Application	Author (refs.)
Binary SSA	BSSA	Benchmark functions	Rizk-Allah et al. [41]
	BSSA	Feature selection	Faris et al. [42]
	BSSA	Feature selection	Aljarah et al. [43]
Modifications of SSA	SMSSA	Benchmark functions	Wang et al. [45]
	SSAPSO	Feature selection	Ibrahim et al. [38]
	ISSA	Feature selection	Hegazy et al. [46]
	I-SSO	Power generation	Sahu et al. [47]
	MSSA	Power point tracking	Yang et al. [48]
	SSA-BCP	Job shop scheduling	Sun et al. [49]
	SSO-PID	Proportional–integral–derivative (PID)	Patnana et al. [50]
Hybridization of SSA	SSA-PID-fuzzy	Proportional–integral–derivative (PID)	Baygi et al. [51]
	SSA-LQR	Proportional–integral–derivative (PID)	Baygi and Karsaz [52]
	HSSASCA	Engineering applications	Singh et al. [53]
	SSA-SA	Classification	Khamees and Albakry [55]
	SSA-HJ	Engineering applications	Asaithambi and Rajappa [57]
Chaotic SSA	CBSSA1–CBSSA4	Benchmark functions	Ahmed et al. [59]
	CBSSA	Graph design coloring	Meraihi et al. [60]
	CSSA	Feature selection	Sayed et al. [58]
	CSSA	Benchmark functions	Ateya et al. [61]
	CSSA	Feature selection	Hegazy et al. [62]
Multi-objective SSA	SSA-RDG-SCBs	Distribution grids	Tolba et al. [65]
	MOSSA	Power system	Wang et al. [54]
	Multi-objective SSA	Power forecast	Jiang et al. [66]
	SSA	Surface electrical systems	Benmiloud ad Arif [67]
	SSA	Parameter extraction	Yousri et al. [68]
	SSA-ENN	Air quality early warning	Hao and Tian [69]
Parameter-less SSA	SSA	Photovoltaic cells system	Abbassi et al. [70]
	WCSSA	Control parameters	Baliarsingh et al. [71]
	SSO	Electrical engineering problem	El-Fergany [72]
	SSA	Control parameters	Zhang et al. [34]
	SSA-PSS	Control parameters	Ekinci and Hekimoğlu [73]
	SSA	Construction parameters	Papadopoulos et al. [74]

3.2 Modifications of salp swarm algorithm

Meta-heuristic optimization algorithms have been utilized widely to address different problems. However, for complex problems, the largest part of the optimization techniques still yields some problems like trapped in local search and be unsuccessful to achieve the near-global solution. This is the purpose of the week of diversification (global search) part in the used technique. Several diversification search strategies are employed by modifying the basic version of SSA to enhance its effectiveness and to assist in preventing the drawbacks. These optimization methods are modifying, hybridization and elitism: the existence of an elite as a dominating element in a system [44].

An enhanced salp swarm algorithm is proposed in [45] based on the simplex method named as simplex method-based salp swarm algorithm (SMSSA). This simplex method is a random variant strategy, which extends a variety of populations and improves the local searchability of the algorithm. This method helps to attain a fitter balancing between the exploration and exploitation searchability of the SSA; in addition, it makes SSA stronger and faster. The proposed method is analyzed and compared with other meta-inspired optimization methods using 4 benchmark functions. SMSSA algorithm is also utilized to one real-life constrained engineering problem. The results

confirmed that the proposed method performed significantly better than the other comparative meta-inspired optimization algorithms.

A hybrid optimization method is proposed in [38] for solving the feature selection problem. This proposed method forms a hybrid of the SSA and the PSO algorithm. The hybridization process is performed between the mentioned two algorithms (SSA and PSO) to design a new version, namely SSAPSO, in which the ability of the exploration and the exploitation search strategies is developed. The proposed approach is examined in two experimental groups. The first group compared the proposed approach using several benchmark functions of similar methods. In the second group, the proposed hybrid approach is utilized to achieve the optimal collection of features using different datasets, where the irrelevant features are excluded from the original dataset while maintaining the performance value or increase. The results confirmed the improvement in the SSAPSO regarding the performance and the accuracy without affecting the computational effort.

A new proposal in [46] called improved salp swarm algorithm (ISSA) based on inertia weight as a control parameter. The proposed algorithm (ISSA) is merged with the *K*-nearest neighbor approach for solving the feature selection problem. Twenty-three UCI benchmark datasets are employed to assess the performance of the ISSA. The ISSA is analyzed and confirmed with the basic SSA and other four optimization methods. The results showed that the introduced approach provided better outcomes than the other comparative algorithms in terms of accuracy value and reduction ratio.

This work deals with load frequency control (LFC) in an islanded two-area AC microgrid (MC) system. This research proposed two different areas, which are the MG system (MGS) and fuel cells (FCs) [47]. MGS includes different microroots, and FCs are actually effective for balancing power generation and load in an interrelated system. MG in the grid-connected method has a lower likelihood of rate handle difficulties due to the current behavior of a use grid, whereas MG in islanded mode handles large recurrence control problem due to the active nature of several renewable energy sources (RES) and various uncertainties. Therefore, the authors proposed a powerful type II fuzzy PID superintendent to provide a second frequency direction loop for controlling both repetition and tie-line power to their nominal values under different uncertainties. The proposed method type II fuzzy PID controller is examined with type I fuzzy controller PI. To get optimal values of PID and PI controllers, an improved salp swarm optimization (I-SSO) algorithm has been performed and the proposed I-SSO technique is compared with original SSA, GA, and PSO. The results demonstrated that the introduced I-SSO attuned type II fuzzy controller gives better performances.

A novel optimization technique named SSA (MSSA) has been proposed in [48]. It is produced by extending the original SSA with various confident salp chains; thus, it can perform an extended exploration and extensive exploitation under the inspire computing structure. For the sake of enhancing the convergence durability, a virtual population-based regroup method is employed for the global controller between different salp chains. The proposed approach is applied for an efficient and effective best power point tracking (MPPT) of PV schemes following PSC. To appraise the MPPT achievement of the proposed approach, four case investigations are conducted using MATLAB. The procured PV system acknowledgments are confirmed to that of eight current MPPT algorithms. The results proved that MSSA got better results than the other MPPT algorithms, which can not only produce the PV system but also provide more energy following various weather conditions in several seasons.

A modified SSA is proposed in [49] based on blocks on critical path called SSA-BCP, to decrease the makespan for reentrant job shop scheduling problem (RJSSP), which is a common NP-complete combinational optimization issue. Then a mathematical model of RJSSP based on the disjunctive graph is built. The extensive reentrant-smallest-order-value (RSOV) encoding rule is built to modify SSA individuals from real vectors to job permutations so that SSA can be utilized to achieve global search for obtaining high-quality solutions or regions in the solution space. Moreover, four sets of neighborhood structures are described after explaining the insert procedure based on block structure, which can be done to avoid search in the invalid regions. Then, a highly effective local search combining multiple neighborhoods is proposed to perform a thorough search from the promising regions determined by the global search. Simulation results showed the effectiveness of the proposed approach.

A salp swarm optimization approach (SSO) is proposed in [50] based on proportional–integral–derivative (PID) controllers for Doha reverse osmosis desalination plant. This plant is interacting with two inputs and two outputs called TITO system. The planet controllers should be operating as follows: Firstly, decoupler is obtained for interacting TITO system to exclude the impact of interaction. Next, two PID controllers, one for each noninteracting loop, are created by reducing the integral squared error (ISE) for the system having decoupler. The simplified decoupling method is used for obtaining the decoupler. The integral of squared error for each control loop is obtained by using two parameters alpha and beta to show the efficacy of the proposed approach-based controllers. Other controllers are also designed using other optimization

methods. The proposed algorithm SSO-based controllers show a superior result in controllers designed rather than the well-known optimization algorithms.

3.3 Hybridizations of salp swarm algorithm

An efficient hybrid control method is proposed in [51] by combining fuzzy logic handle and the proportional–integral–derivative (PID) controller. The suggested PID-fuzzy handler approach, with the characteristics of the PID handler, is easy to execute in reducing vibration on structural methods. The authors use an algorithm procedure based on the SSA and then compare with fuzzy logic handle and LQR handle. The PID-fuzzy handler is designed for a building with four levels of freedom equipped with powerful tuned mass damper (ATMD). To assess the production of the proposed SSA-based PID-fuzzy handler, extreme data of three earthquake area motions have been acknowledged. Results are analyzed with the fuzzy handler and LQR handler to confirm the better achievement of the SSA-based PID-fuzzy handler. The simulation and results revealed that the proposed PID-fuzzy works better than the other comparative methods which are examined in decreasing the amplitude of seismic acknowledgments of the arrangement in terms of displacement and velocity of all novels of the structure.

A hybrid control method is proposed in [52] by getting a linear quadratic regulator (LQR) handle approach and the proportional–integral–derivative (PID) handler. The suggested PID-fuzzy controller approach, with the features of the PID handler, is simple to execute in reducing vibration on structural methods. This method uses optimization arrangement based on a new algorithm called SSA; the proposed algorithm is analyzed and compared with four algorithms to perform the SSA-based PID-LQR effectiveness, and the LQR-PID handler is designed for a building with four levels of freedom provided with an ATM damper. To assess the effectiveness of the proposed SSA-based LQR-PID handler, real data of EL have been examined. To prove the effectiveness of SSA-based LQR-PID handler than the other comparative algorithms, the proposed algorithm is analyzed and compared with LQR-PID handler and LQR handler which is optimized by four other algorithms such as PSO, WOA, ant lion optimizer (ALO) and ABC. The simulation and study results showed that the LQR-PID works better than the other comparative algorithms which are analyzed in decreasing the amplitude of seismic acknowledgments of the building in regard of displacement of novels of the building.

A hybrid algorithm is proposed in [53]; it combines the SSA with sine–cosine algorithm (called HSSASCA) to improve the convergence effectiveness with the global search and local search being better to other comparative test algorithms. This approach uses the space equations of sine–cosine to modernize the position of SSA in the search space; hence, the feasible optimal solutions are accomplished based on the sine–cosine algorithm. Within this procedure, each salp utilizes the information of sine–cosine algorithm to enhance their global and local search capability. To enhance the basic strategy, to avert premature convergence, and to better control the search toward the feasible search space, a combined version is incorporated in SSA. The proposed algorithm is proved on twenty-two standard functions and three applications, the 3-bar truss, cantilever beam design problems, and tension/compression spring. The results showed that the proposed algorithm (HSSASCA) performed better regarding the runtime in opposition to the other algorithms.

The efficient load forecasting for power system outlining and operational decisions are presented in [54]. Forecasting accuracy through impacts the safety and economy of the power system are studied. Obtaining the requested point forecasting precision has been perceived as a challenge because of the natural complexity and change of the power load. To overcome the challenges of critical point forecasting, the period prediction is fitted to allow extended problem and provide more information for efficient operation judgments. A hybrid system is proposed in [54] for short-term load forecasting (STLF) by combining a multi-objective optimization algorithm, data preprocessing steps, and an interval prediction method. In this proposal, the training method is achieved by maximizing the coverage chance and by minimizing the forecasting period width at the same time. Furthermore, a hybrid lower upper bound evaluation (LUBE) based on multiple objectives is proposed. Furthermore, a hybrid model including data preprocessing, Elman NN, multiple objectives, and SSA. In this way, such a hybrid design can reduce the influence of noise in a dataset and the parameter optimization rule is more rich and effective in Elman NN. To confirm the effectiveness of the proposed approach, half-hourly load data are produced as sample problems and two experiments are conducted in four groups. The simulation results revealed the superiority of the proposed system, and the impacts of the sub-modules were measured by examining the results with those of benchmarks. Furthermore, it is showed that the proposed system is important in enhancing power grid management.

A new proposed method utilized the pure SSA in [55] for solving dimension, reducing and removing noise from a huge dataset; this can be done through picking the best subset attributes on the source of particular criterion and improving the fitness of classification efficiency. Other work hybridized SSA with simulated annealing (SA) technique called SSA-SA. In this proposal, SSA is applied as an inner function to develop the exploitation search

capability that is utilized to take a defective quality solution than the current solution [56]. The effectiveness of the proposed approach is evaluated on 16 datasets including two groups of high-dimensional data from the UCI repository and compared with the pure (SSA) and other methods. The results showed that the proposed method gave better results. SSA-SA gave a better performance as a multi-objective where produced two different objects, maximal accuracy of classification with a minimal size of features on all datasets.

An automatic design approach is presented in [57] based on a swarm intelligence algorithm for complementary metal–oxide–semiconductor (CMOS) analog integrated circuit (IC). A hybrid algorithm called SSA is used for finding the optimal sizing of a CMOS differential amplifier and the comparator circuit. Furthermore, the hybrid SSA is implemented to optimize the circuit design parameters and to reduce the MOS transistor volumes. The proposed hybrid method is applied for automated design and optimization of CMOS analog ICs utilizing generic process design kit (GPDK) 180-nm technology. To investigate the effectiveness of the proposed hybrid method, several comparisons have been made by comparing with other simulation-based circuit design methods. Hybrid SSA-based CMOS analog IC designs proved that it got better performance than the previous comparative studies.

3.4 Chaotic salp swarm algorithm

SSA is kind of the various recently introduced optimization algorithms motivated by the imitation behavior of salp groups. However, matched to the other optimization algorithms, SSA falls in stuck during the local research and weak convergence speed [58]. Lately, chaos method has been strongly utilized for resolving these mentioned problems in that algorithm (SSA) [59].

A new chaotic binary of SSA is introduced in [60] called CBSSA. This proposal is to tackle the graph design coloring optimization problem. First, the proposed CBSSA is taken from the SSA alongside with the *S*-shaped change function and the binarization method. Second, the important chaotic system (map), namely the logistic map, is utilized for repairing the random values or decisions worked in the mathematical representation of SSA. The purpose of using a chaotic system is to avert the stuck in local search and improve the exploration and exploitation of search capabilities. They applied the common DIMACS benchmark datasets for assessing the achievement of the proposed method. The results proved that the proposed method get better results related to the other results gotten from common algorithms in the literature.

A novel hybrid SSA and chaos system are proposed in [58]. The suggested algorithm is employed on fourteen different benchmark functions and twenty datasets. Ten various chaotic plans are used for improving outcome accuracy and convergence speed. The results showed that the proposed algorithm is promising. Furthermore, the results revealed that the capability of the chaotic systems or plans in finding an optimal subset of features is powerful, which search for the high accuracy value and low size of the features subset. Furthermore, the results convey that the proposed system is the optimal plan of the applied ten algorithms, which can increase the efficiencies of pure SSA.

Software-defined networking (SDN) is a new system model that allows flexible control for networks. But, with the rise in network range, a single controller of SDN has numerous definitions on both scalability and performance. Assigned multi-controller diffusion is an encouraging way to perform fault sophisticated and scalability. There are still exposed research problems associated with controllers position and the optimal amount of extended controllers. A dynamic SSA with the start of chaotic maps is developed in [61] called SSOA; it is developed for improving the optimizers production (performance). The algorithm dynamically estimates the optimum amount of controllers and the optimal connections between controllers and switches in wide-scale SDN networks. To assess the proposed algorithm, various experiments were carried out and performed in various scenarios. Moreover, the algorithm was analyzed with other published meta-heuristic optimization algorithms. The results proved that the proposal exceeded the other comparative methods and a game system-based optimization algorithm in terms of computational time and security.

Despite high production of SSA, getting stuck in local optima and slow convergence speed are couple big drawbacks of SSA. A novel combined method, chaotic plan and SSA algorithm (CSSA), is introduced in [62] to avert the mentioned drawbacks of SSA, where chaotic plans are employed to improve the effectiveness of SSA. The proposed algorithm is combined with the common classifier (i.e., *K*-nearest neighbor) to tackle the problem of finding informative features. Twenty-seven benchmark datasets have been utilized to evaluate the effectiveness of the proposed method. The results proved that the proposed algorithm (CSSA) yielded better results analyzed to pure SSA and different published methods.

3.5 Multi-objective salp swarm algorithm

Multi-objective algorithms have multiple objectives, which are often in conflict. Multi-objective optimization is a field of multiple criteria decision making that is regarded with mathematical optimization problems including more than one objective function to be determined concurrently.

Multi-objective optimization has been used in many fields of science such as in engineering, cloud computing, and economics, where optimal judgments require to be used in the presence of trade-offs among two or more conflicting objective functions. Minimizing the number of selected features while maximizing the performance of the underlying feature selection algorithm for finding the optimal features. In real-life problems, there can be more than two objectives [63, 64].

SSA is applied in the context of electric power networks in [65]. It used to handle the optimization problems of large power losses and lower-voltage profile in distribution grids. Therefore, to enhance voltage levels, to minimize the distribution lacks, the whole yearly operation damages by the means of incorporating renewable shared generators and shunt capacitor series. So, SSA is applied to solve the optimization of finding the optimal sizing of renewable shared generators and shunt capacitor series. The experimental methodology is applied in two basic parts: Part I, to examine the effectiveness, applicability of the proposed paradigm through conducting a comparative study between the proposed SSA and other techniques, and Part II, to ensure the quality of the proposed optimization model through discovering the most excellent status that guaranteed the smallest power damages and high of voltage level, and energy savings. The former reported methods are tested by applying various values of the weighting parts of the chief objective functions MOFI on 33-bus IEEE RDN partitioning grid. The analysis result indicates the superiority of SSA over other techniques and it obtained the optimal explications. Later, the analysis results showed that the proposed SSA technique produced the minimal system lacks power and energy and the whole operating damages adequately.

A multi-objective SSA and a hybrid interval prediction system are applied in [54] to solve short-term load forecasting (STLF) problem called MOSSA. The system aims to present powerful technical and efficient support for judgment making and command in power networks. It combined the data preprocessing method, an optimization method, and a prediction method. MOSSA is applied in the optimization method to set the struggle between larger coverage probability (CP) and deeper prediction interval width (PLW) and to train the parameters in a neural network. An experimental approach is employed for validating the effectiveness of the proposed hybrid system. The simulation outcomes reveal that applying MOSSA provides a powerful CP and a moderate interval width at the equal time, which proceeds up for the deeper CP and extraordinary interval width of common methods. Also, the results indicate the validity and applicability of the proposed method to provide more accurate results that can be used for improving power grid management.

A composite forecasting framework is developed for the reported power forecast based on the reported power features. The proposed framework is based on a novel multi-objective method that aims to determine the upper and lower limit lines of the future reported speed concurrently [66]. The multi-objective SSA is utilized to find the balancing in between tuning the key parameters of the machine learning approach to invent the forecasting engine. The forecasting effectiveness of the proposed framework is validated using a case study approach with three real datasets. The analysis result of the case study revealed that the integrated of multi-objective SSA with the proposed method achieved better wind speed interval prediction than the single-objective algorithms.

A hybrid of SSA and SA approach is introduced in [55] for discovering and classifying knowledge in large-scale data. The main goal of integrated salp swarm with simulated annealing is to improve the exploitation capability of the original SSA. The experimental approach has been carried out to confirm the applicability of the proposed approach. The experimental results were assessed on sixteen benchmark datasets that contain two large dimensions from the UCI repository. The experimental outcomes indicate that the proposed approach has equal results in terms of production in the complicated search space as a multi-objective optimization where gained two contradictory targeted, the smallest size of features with maximal classification precision on all utilized datasets. Furthermore, the proposed approach enhanced the exploitation experience in the SSA and provides escaping from local search.

A new approach is introduced in [67] to decrease the dynamic equivalence order of surface electrical systems. This approach started by performing a revolution in the internal operation, followed by designating the system acknowledgments (e.g., energies, electrical controls, and angular velocities), and lastly estimating the parameters of the ES based on reported signals. However, to select the best parameters of the equivalent generator that preserves power circles at tie lines and electrical control of associated dynamos in the maintained system, the multi-objective SSA is utilized. The experiment was conducted to validate the nature of the proposed approach to control the dynamics of the original scheme. The results showed that the multi-objective SSA has a precision ability to show the aim of the new system.

The SSA is applied along with several recent optimization techniques in [68]. The proposed algorithms are run over four different objective functions (e.g., mean square error, integral of squared error, integral of absolute, and time absolute errors). The study aims (1) to examine the most suitable optimization methods in terms of parameter extraction of three fractional-order chaotic

systems and (2) to investigate the most appropriate objective purpose that encourages the algorithms to obtain more precise and consistent decisions. Experiment-based approach is carried out for the purpose of determining a new fitness combination (algorithm and objective function) that offer more accurate result in such complex systems. To achieve this, the experimental results of the algorithms and objective functions are tabled and compared. A comparative results between the algorithms revealed that salp swarm algorithm is the second-best algorithm in terms of selection the parameters of the 3 chaotic modes in the existence of judgment noise using couple objective functions. In addition, the comparison produces shown that SSA has the least values of relative error curves above the number of samples with the other comparative methods.

A novel hybrid system is developed in [69] for air quality early warning. The system consists of 4 approaches: data preprocessing approaches, optimization approach, forecasting approach, and evaluation approaches. In the forecasting approach, multi-objective SSA is used to find the optimal initial weights and thresholds of the neural network. SSA aims to obtain better precision and stability in air feature prediction. The applicability and performance of the proposed multiple steps before air quality early warning system have been tested by carrying three experiments. The experiments were conducted in different environments which included three selected study areas including industrial development, geographical area, and climatic portions. The experimental results reveal that the integration of SSA along with other modules help to achieve better forecasting effectiveness than other benchmark approaches.

3.6 Parameter-less salp swarm algorithm

An evaluation model is implemented in [70] to estimate the parameter of photovoltaic cells system. They employed the SSA in order to extract the parameters of the electrical similar path of the photovoltaic cell double-diode pattern. The experimental approach is used to measure the effectiveness and to examine the effectiveness of SSA. For example, to measure the effectiveness of SSA the experimental results are analyzed with other competitive methods. The comparative results showed that SSA is offered the best result over these algorithms in terms of convergence speed and nature of photovoltaic cell parameter extraction. To test the performance of SSA, several evaluation measures are utilized. However, the results indicated the better efficiency of the SSA-based optimizer as opposed to all other published methods.

The SSA is employed in the field of gene selection and cancer classification [71]. SSA is used to enhance the effectiveness of kernel extreme learning machine KELM algorithm. This is done by addressing the problem of selecting the optimal kernel and control parameters of KELM from huge search space efficiently. In addition, it used to choose the optimal value of the gene subset. The proposed model is confirmed in terms of ranking accuracy and efficiency. To validate the classification precision, several evaluation measures are utilized such F-measure. The experimental results of the introduced model are analyzed with pure SSA, PSO, and GA algorithms after they incorporated in KELM. However, the comparison result indicates that the proposed model yields into more accurate classification result than other models.

SSA is applied in [72] to solve the electrical engineering problem. In the proposal, a model-based SSA is performed to determine the best value of foreign parameters of polymer exchange membrane fuel cells. Enhancing the polymer transfer membrane fuel cell modeling implies a complex model due to the level of nonlinearity and multiple variables. Therefore, the SSA is applied over other conventional approaches due to its efficiency to deal with such a complex problem. To prove the effectiveness of the proposed model, two test instances of typical commercial PEMFC stacks are used. In the first test case, the simulation results of the SSA in comparison with grasshopper optimizer and genetic algorithms along with the corresponding squared deviations reveal that SSA produced the minimum squared deviations over other algorithms which indicate very fast convergence characteristic, while in the second test case, the simulation results of the SSA in comparison with gray wolf optimizer and dynamic electrochemical produced the minimum squared deviations which indicate very fast convergence characteristic.

SSA is used in [34] to solve the soil water retention problem by minimizing the variance between the evaluated and the expected water content. Applying the traditional method in such a complex problem head to be time-consuming, and may point to higher errors. SSA is applied for the parameter calculation of the soil water holding curve model (e.g., van Genuchten model). The benchmarking study was conducted to assess the performance of the proposed algorithm. The SSA results are compared with several powerful optimization algorithms and the RETC plan. The conducted experiment included 9 various soil samples that contain 8 soil textures in order to ensure the generalizable of SSA. The comparative results showed that SSA gave better than the other comparative methods.

SSA is used to optimize the power system stability analysis problem in [73]. The application of SSA-based power system stabilizer (PSS) is designed in order to search and select the suited setting of PSS parameters. Such application aimed to develop the balance of a multi-machine power mode using PSS in which parameters are attuned by the SSA. The performance and ability of the

proposed application were tested using the experimental approach. The performance of SSA-based PSS application is measured by considering the Western Model Coordinated Council (WSCC) 3-machine 9-bus power. The results of SSA-based PSS application are compared with two optimization algorithm, namely biogeography-based optimization and tabu search. The experimental results showed that SSA technique has excellent convergence rate than other methods. The effectiveness of the proposed SSA-based PSS application was evaluated by general nonlinear time-domain simulation investigations under a huge disturbance. The simulation results with SSA-based PSS application are better than those of the other two methods in terms of the overshoot and settling time.

SSA along with nonlinear least squares, particle swarm optimization, salp swarm algorithm, moth-flame optimization, and genetic algorithms is applied in [74]. This proposal is found to measure and investigate the two-layer earth construction parameters from measurements. This is aimed to (1) implement a reliable and effective design of electrical grounding methods and (2) define an absolute calculation of the per-unit-length parameters of above-ground transmission lines and underground cable methods. Experiment-based approach is conducted for the purpose of determining a new fitness combination (algorithm and objective function) that offers more accurate result in such complex systems. The experimental results showed that among all tested optimization algorithm, the genetic algorithm is selected for the selection of the parameters of the two-layer earth structure, taking into account the soil seasonal variation. However, it is worth mentioning that the authors did not affirm the decision that the genetic algorithm is the best optimization algorithm to handle such a problem, but additional research on this issue is still needed.

4 Applications of salp swarm algorithm

Many applications of SSA have been reported from various fields. For instance, SSA has been employed to solve benchmark optimization and real-world problems. More details of the SSA applications are illustrated below. A brief summary of the main applications of SSA is shown in Table 3.

Table 3 Summary of SSA applications

Applications	Name	Author (refs.)
Feature selection	BSSA	Aljarah et al. [43]
	SSA-FS	Aljarah et al. [76]
	SSA	Ahmad et al. [59]
	SSA	Hussien et al. [78]
	IABSR	Zhang et al. [79]
Training neural networks	ANN	Esfe et al. [80]
	SSA	Bairathi et al. [81]
	SSA	Abusnaina et al. [39]
Scheduling	SSA-BCP	Sun et al. [49]
Control of power systems	FOPID	Mohapatra et al. [83]
	SSO	Sahu et al. [84]
	SSA-OPF	El-Fergany et al. [85]
	SSA	El-Fergany et al. [85]
	SSA	Guha et al. [86]
	SSWO	Kuyu et al. [87]
Renewable energy system	SSA	Rezk et al. [88]
	PSO-GSA	Mohamed et al. [89]
	SSA	Barik et al. [90]
Other applications	SSA	Liu et al. [94]
	SSA	Khalid et al. [95]
	SSA	ERDO et al. [97]
	SSA	Asasi et al. [98]
	SSA	Sereshki et al. [99]

4.1 Machine learning applications

4.1.1 Feature selection

Bio-inspired meta-heuristic algorithms were broadly employed to solve various optimization problems such as feature selection, which is an important preprocessing step that can affect the efficiency of data mining methods [75]. Seeking for an optimal subset of features among the whole dataset is a complex problem, especially for big datasets.

In [43], the authors introduced a new leadership composition which contains a binary SSA and asynchronously updated controls. The purpose of work is producing optimal leadership construction; several comprehensive simulations are performed to find the most effective leaders in the search space of the artificial salp series. Motivated by the behavior of a termite colony by dividing them into four classes, split the salp series into several sub-chains. Thus, each sub-series of the salps can update their locations by following a distinct strategy. It is worth mentioning that the authors used three various updating strategies. Twenty well-known datasets from the UC Irvine machine learning repository are examined and verified by the proposed algorithm. The experimental results and analyses verify that employing a part of the salps as leaders of the series can efficiently enhance the execution of SSA in terms of accurate measurement. Moreover, the single parameter of SSA is tuned dynamically to improve its efficiency in investigating the search area in dealing with various datasets of the feature selection.

Ibrahim used SSA to solve the feature selection problem, called SSA-FS [76]. SSA-FS was examined with the PSO algorithm and DE in terms of the performance with two main criteria, which are accuracy and runtime. Real datasets of bladder and colon cancers are collected from Iraqi hospitals for breast, as well as synthetic datasets for the validation results of SSA-FS. In comparison with other well-known algorithms in the literature for both real and synthetic datasets, they have found that SSA-FS obtained the highest accuracies values with less runtime.

The classification algorithms are sensitive especially in high-dimensional data. High dimensionality makes many problems to the used classifier like over-fitting and high time-consuming. Feature selection is used to solve both mentioned problems. The goal of this solution is to decrease the number of noninformative features by ignoring the noisy, redundant, and irrelevant data, at the same time to try to maintain an agreeable classification accuracy. FS is used to express as an optimization problem. SSA was shown better performance in solving this variety of problems. Thus, Ahmed et al. proposed a chaotic version of SSA [59], which is one of the recent successes of metaheuristic algorithms. The authors introduced four various chaotic maps to achieve the balance between the exploitation and exploration in the proposed version. The proposed methods were assessed using 12 real datasets. The experimental results reveal that the chaotic maps enhanced the effectiveness of the SSA and achieved better results compared with the other methods in the literature.

The support vector regression has been used to deal with the problem of the stock price forecasting. Nonetheless, the selection of suitable kernel parameters is critical to achieving competent forecasting performance. In this research [77], a novel approach is proposed for solving the forecasting stock prices problem by mixing the support vector regression with the firefly algorithm. The proposed model has performed over two stages. Firstly, a modified firefly algorithm (MSA) is produced to improve the global convergence speed, in which the dynamic adjustment and the opposition-based chaotic strategies are presented. Secondly, a hybrid support vector regression model is introduced and combined with the proposed modified version (MFA) for solving the stock price forecasting problem, in which the MFA is employed to optimize the support vector regression parameters. The performance of the MFA is compared with several recent algorithms such as FA, GA, and SSA. Comparative experiments are carried out to prove the applicability and superiority of the proposed approach.

The growing size of the chemical domain of chemical synthesis databases and the importance of resemblance criteria to drug detection are the essential points in cheminformatics study. Consequently, Hussien et al. [78] utilized SSA for foretelling chemical compound movements. The proposed work aims to describe the chemical composition by three initialization, such as large, small, and mixed initializations. Also, for the fitness function of SSA, the *K*-nearest neighbor (KNN) has been used to select some of the beneficial features with achieving better classification accuracy value. The results show the ability of SSA to achieve the optimal features that maximize the value of the classification performance and reduce the number of chosen features. Also, it obtained a superior accuracy value compared with other algorithms that used the same data.

Machinery status controlling and defect diagnosis are very important to make sure the reliability and functionality of equipment and to avoid the future problems. The vibration signal of the machinery is a conventional method with multiple probabilities and high error features. To precisely obtain fault features, SSA has been used to obtain the optimal bistable stochastic resonance and empirical wavelet transform for enhancing the weak features [79]. The proposed method provides complete employment of the signal decomposition effectiveness value of empirical wavelet transform and the signal improvement in the proposed approach to obtain the aims of fault feature improvement in the low-frequency collection of the fast Fourier transform spectrum. Firstly, the empirical wavelet transform is applied as the preprocessing steps of dividing the vibration signal into small sub-components. Next, the sensitive element that includes major fault information is more input into the bistable stochastic resonance system to improve fault features with the support of remaining noises. After that, the fault features are distinguished from the fast Fourier transform spectrum of the bistable stochastic resonance output by using SSA. Compared with the original bistable stochastic resonance, the original approach not only optimizes the bistable stochastic resonance method parameters but also includes the calculation step size. On machinery fault diagnosis, two cases studies are used to measure the effectiveness and robustness of the proposed method.

4.1.2 Training neural networks

This section highlights on using SSA with an artificial neural network (ANN), which is an analytical sample depends on computational intelligence [80]. ANN simulates biological neural networks (i.e., represents the connection between a group of biological neurons). Likewise, an ANN is a set of interconnected of artificial neurons using intelligence computation methods. ANNs are successfully utilized to perform classification, pattern recognition, and various other machine learning techniques.

ANNs have achieved robust results in the statistics field, computer science, and computational intelligence applications. One of the more public and simplest ANNs is the feed-forward neural network (FNN), where it is able to solve nonlinearity problems. Bairathi and Gopalani employed SSA with FNN weight [81]. The performance of the proposed method is assessed using several benchmark datasets and compared with various well-known published meta-heuristics algorithms.

The most popular and successful techniques of ANN called pattern classification. Traditional training algorithms have some weaknesses. For instance, slow convergence and traps in the local minima. Hence, several optimization algorithms such as SSA are applied to solve these problems. In [39], SSA is introduced to obtain the optimal coefficients for the neural networks, which leads to achieving better pattern classification. The benefits of the proposed approach are approved utilizing a set of common classification problems. The obtained results reveal that the proposed technique gives better results than the other comparative methods in terms of classification accuracy measure and sum squared errors.

4.2 Engineering applications

SSA was employed in several optimization problems, where most of these problems are located in engineering applications, such as scheduling, control of power systems, and renewable energy system. The following sections illustrate the effectiveness of SSA in engineering applications.

4.2.1 Scheduling

The scheduling is very important for controlling, arranging, and improving work. Thus, there are many benefits of scheduling, such as improved efficiency and saving time, cost, and effort. Consequently, many types of research utilized the scheduling to solve their problems. For example, Sun et al. introduced SSA based on blocks on critical path (SSA-BCP) to minimize reentrant job shop scheduling problems (RJSSP) [49]. The authors divided the work into three main steps: (1) assuming that the problem has reentrant features, a reentry arc is added to the disjunctive graph model of JSSP, and the RJSSP mathematics planning model based on disassembly graph is established; (2) designing an expanded reentrant-smallest-order-value (RSOV) which help the SSA to perform a global search for discovering the regions in the solution space or determining high-quality solutions; and (3) proposing a highly efficient local search integrating multiple neighborhoods for applying a comprehensive search using the promising regions which are mentioned in the previous step.

4.2.2 Control of power systems

In the power and energy system, a suitable control system that helps to provide safe and fast procedures to generate power, also to guarantee a better quality of energy service for the recipients. The main concept in the power system control called automatic generation control (AGC), wich contains a number of elements that regulate various quantities, for example voltage, frequency, and interline power exchange [82].

Mohapatra and Sahu utilized SSA to find the fractional-order parameters and best gains [i.e., differentiator order (μ) and integrator order (λ)] of the designed fractional-order proportional–integral–derivative (FOPID) monitoring [83]. It is worth mentioning that the authors introduced FOPID to solve the load on control problem between two interconnected regions: battery storage and multi-source power system. The results showed that the performance of SSA provides a greater dynamic performance of optimizing FOPID controller by achieving minimal settling time compared with other controllers.

The same aim of using the SSA has been done in [84], where it introduced to determine globally optimal solution in the multistage proportional derivative with filter (PDF) plus $(1 + \mathrm{PI})$ controller parameters for AGC in various source types of two locations of nonlinear electrical networks. The main objective of this work to ensure that the system factual and nonlinearity, where a generation rate constraint (GRC) of 3% is considered in each location. Regarding the SSA, the authors employed it to improve the performance in the classical controller such as PI and PID controllers. Also, the performance of SSA has been tested in different environments (i.e., exploitation and exploration). Finally, in the convergence rate, the results illustrated that the SSA outperforms other optimization techniques.

In [85], El-Fergany and Hasanien focused to solve optimal power flow (OPF) problem by using SSA to optimize four fitness functions: (1) stability of the static voltage (VS) of electric power systems, (2) gross the real power losses of the network, (3) total of consumed fuel costs, and (4) the entire total of voltage variation of load buses. The VS has been highlighted based on a modal analysis which considered as an objective function. The strong VS is related to the magnitude of eigenvalues, where the relation between them is positive (i.e., increasing the magnitude of eigenvalues leads to strong VS). The results of simulations showed that the SSA confirmed its effectiveness and robustness compared with other algorithms for determining the OPF solution under the same conditions.

SSA is proposed to optimize the cascade tilt–integral–derivative controller (CC-TID) for load frequency control of connected power systems (IPSs) [86]. SSA is utilized to

keep track of the optimal tunings of the CC-TID controller by the reducing of area control error (ACE). The proposed work can be used for control strategies, especially for detecting the system frequency. The simulation results showed that the performance of SSA outperformed other optimization algorithms such as PSO, DE, FPA, and GA in terms of determining the minimum objective function value, typical transient specifications, and convergence rate. In addition, the superiority of SSA: CC-TID controller over SSA: TID and FPA: PI-PD controllers.

In the electrical power systems, reactive power optimization is considered as the most complicated problem, where it includes a wide range of solution space. Moreover, the problem is nonlinear and nonconvex. Kuyu and Vatansever proposed three recent techniques: Yin–Yang pair optimization, whale optimization, and SSA to fix the optimal reactive power dispatch (ORPD) problem for real power transmission loss [87]. The specific purpose of using the optimization techniques is to find the optimal control variable settings. The IEEE 14- and 30-bus systems are utilized to evaluate the performance of the proposed techniques. The results illustrated that all proposed techniques are able to determine the optimal values for the system parameters with a preference to SSA.

4.2.3 Renewable energy system

Solar photovoltaic (PV) is a major and effective resource of renewable energy, because it is easy to get, as well as its eco-friendly nature [88]. Therefore, solar PV energy systems become an interest in the present researches. Mohamed et al. introduced different meta-heuristic techniques (i.e, moth-flame optimization (MFO), gray wolf optimization (GWO), and hybrid particle swarm optimization–gravitational search algorithm (PSO-GSA), in addition to the basic SSA) to determine the maximum power point (MPP) [89]. The experiments are divided into two categories: (1) convergence speed and the time to find MPP, where the results demonstrated the superiority of GWO followed by SSA, MFO, and PSO-GSA, respectively, and (2) the sensitivity analysis, where the results demonstrated the successful rate, tracking efficiency, and robustness of PSO-GSA technique outperformed with GWO, MFO, and SSA.

Barik and Das used SSA to optimize the load frequency control for managing the effective power of the separated renewable microgrid generating power from rooftop solar arrays, fuel cells, biomass-fired combined heat and power, and aqua-electrolyzer [90]. The purpose of this work is power and waste management by generating power from solar irradiances, sewage waters, and urban solid wastes. Thus, this work is the guaranty of continuing the power even in case the climatic changes.

4.3 Image processing

Image processing illustrates beneficial information from the image to improve its view by changing it into a digital shape and then implementing some operations. However, there are different problems in terms of efficient search which should be performed in a complex search domain to find an optimal solution [91, 92].

Fish image segmentation is the basic step in the fish recognition. Also, it can be applied in the fields of aquatic product processing, fish behavior, fish identifying, and classifying. It is worth mentioning that the fish image segmentation faces some challenges such as various specimens, illuminations, positions, rotations, and the backgrounds existing in fish images. Therefore, Ibrahim et. al proposed a new segmentation model using SSA for fish images [93]. The authors employed the SSA to optimize the initial parameters for simple linear iterative clustering (SLIC) method, which it used (i.e., SLIC) to create compact and nearly uniform superpixels. After that, they utilized Otsus method to help in thresholding to find satisfactory solutions of extracted fishes from the original images.

4.4 Other salp swarm applications

To solve this type of optimization problems (i.e., the nonlinear optimization problems of time difference of arrival passive location), a new target localization scheme based on SSA is proposed in [94]. Firstly, it utilizes a new population update paradigm to fully balance the exploration and exploration performance and growth SSA behavior during the iteration process, which not only guarantees the search of the overall position and the variety of individuals but also increases the performance of the problem that other optimization algorithms are simply stuck in local optima. Second, SSA has very few parameters and the computing rate is obviously developed. Finally, the convergence rate of the SSA is very stable and the accuracy of positions updating is higher. The simulation results proved that the proposed SSA quickly and stably converges to the optimal position in the problem of time difference of arrival passive location, compared with others published algorithms; SSA has notably higher location accuracy value.

The demand response (DR) program is used to improve the energy consuming pattern of the customer with the development of the performance of the energy support. The cost infrastructure of the DR is an active dynamic program (time-based). It has complicated advantages containing demand, seasonal parameters, and marginal costs. There is a difference in the DR cost scale. Sometimes costs reach

high (peak load); this occurs when the need for generation capacity is less than the power services. The major purpose of DR is to assist the user to change the peak load and receives incentives by reducing the cost. Nevertheless, prices continue the equivalent for each one of the consumers in both changing the peak load or not. Therefore, Khalid et al. enhanced time-of-use electricity price rate using game theory [95]. The work aims to determine the rates for shoulder-peak and on-peak hours. The appropriate load is used to determine the price for each beneficiary. The first step of the work is proposing a method is investigated utilizing the time-of-use pricing system. Eventually, it is assessed employing a day ahead real-time pricing schema. Furthermore, changing the load from on-peak hours to off-peak hours leads to a defect in off-peak hours. Thus, the authors examined the influence of SSA and rainfall algorithm on the beneficiary electricity bill and PAR after listing. The results proved the effective performance of the proposed approach.

The development of the demand response program optimizes the power consumption pattern of clients and develops the ability of energy supply. The pricing support of the DR program is a time-based charge where prices increased according to user way. The difference in price rate is due to the use of electricity and another generation cost. The main aim of demand response is to help the user to groups the peak load and receive purposes in terms of cost reduction: users who change the load and who did not have to give the same price. In this research [96], a game theory-based pricing approach is assessed where each user has various price rates based on the use of energy during shoulder-peak and on-peak hours. Furthermore, to avert peek formation through the off-peak hours SSA is utilized to schedule the various home appliances. The experimental results showed the performance of the proposed scheme as well as proposed scheduling home appliances scheme.

The aims of work in [97] are to present recent nature-inspired optimization algorithms and to examine the effectiveness of them. Several well-known benchmark test problems (i.e., two uni-modal, and two multimodal) and four nonlinear equations systems were utilized for comparison purposes. The results were presented. It was observed with these test results, cannot tell that one of the selected algorithms outperforms. But all of the algorithms can be a dilemma for tacking the nonlinear equation systems.

Asasi et al. [98] introduced a novel method for tackling the simultaneous optimal distributed generators and shunt capacitor status problem in order to reduce active power losses. SSA is inspired by the swarming movement of salps in oceans; it is executed to find the optimal solution to solve this optimization problem. The proposed method is applied to 33- and 69-bus test systems. The achieved results have been examined with other existing well-known approach so that the comparisons proved that the performance is good as well as the effectiveness of the proposed approach to find the global optimum solution.

The metal strips with the optimization of mechanically stabilized earth wall have been investigated [99]. There are three swarm optimization algorithms (i.e., SSA, GWO, and PSO). To this end, a code was generated to display the mechanically stabilized earth well based on FHWA regulations. Because of the importance of mechanically stabilized earth wall length in the design, the authors employed four various heights of the wall for analyzing. The effectiveness of the proposed algorithms is evaluated based on reducing the cost (i.e., the fitness function). Impact of differences in unit costs of higher mechanically stabilized earth structure materials on cost duty is assessed. The experimental results showed that the cost reductions associated with the PSO and GWO are higher than that achieved by SSA.

5 Assessment and evaluation of salp swarm algorithm

As reviewed above, the SSA has been widely utilized to solve a variety of optimization problems since the proposal. The simple inspiration, few controlling parameters, and adaptive exploratory behavior are the essential reasons for the success of this algorithm. The similarity to other proposed stochastic optimization algorithms, however, it has a number of limitations and suffers from unavoidable drawbacks.

The main limitations and restrictions come from the sharpened no free lunch theorem in search and optimization (NFL theorem), which states that no optimization algorithm is able to solve all optimization problems. In other words, the effectiveness of all optimization algorithms equalized over any finite set F of benchmark functions is equivalent iff (if and only if) F is achieved under permutation and each objective function in F is evenly likely. This means that SSA may need modification and change when solving some real-world optimization problems. Another limitation is the objective function (i.e., single-objective nature) of this algorithm that enables it to solve just single-objective optimization problems and the other objective function (i.e., multi-objective nature) of this algorithm that enables it to solve just multi-objective optimization problems. The objective function should be provided with special operators to solve binary, discrete, continuous, dynamic, multi-objective and other problems.

The main drawback of SSA is the low ability to control the difficulties of multimodal search strategies, as it seems that all three parameters (i.e., a, v and F) tend to converge

to the corresponding solution. Adding more irregular (random) components to convert the solutions during the optimization process will increase the chance probability of finding a global optimum solution when solving hard multimodal problems. The effectiveness of the SSA diminishes noticeably equivalent to the number of variables. This is possible because of the trick of the initial population (solutions) in a local optimum solution when solving such optimization problems. At the moment, there is no special director or operation to resolve such local optima slumps in the literature.

The authors of SSA conducted a comprehensive experiment and recognized that studying four groups of results in the best average effectiveness (performance) on standard benchmark problems and a set of normal dimensional real-world problem. However, considering more fewer groups is needed when solving medium- or large-scale problems. Last but not least, the fast convergence rate\speed and stimulated exploitation to head to local optimum solutions when solving hard optimization problems with a large number of options and local solutions. Mechanisms should be contrived to decelerate the convergence rate and exploitations processes if the algorithm is stuck in local solutions. Adaptive mechanisms are useful tools in this respect to adjusting the convergence speed relative to the number of enhancement iterations of the quality of the best solution reached so far.

6 Conclusion and possible future directions

In this review paper, over 70 research articles were collected, studied, and analyzed to highlight the advantages and disadvantages, robustness, and weaknesses of SSA for researchers interested in the meta-heuristic optimization algorithms. This review comprehensively and exhaustively summarizes references published from 2017 until the beginning of 2019. Most of these articles described the variants of SSA, where the proposed versions of SSA support to improve the performance of the original SSA to solve different types of optimization problems, for instance binary, modifications, hybridizations, chaotic, multi-objective, and parameter-less of SSA. Furthermore, introduced the applications of SSA in various fields, for instance machine learning (i.e., feature selection and training neural networks), engineering (i.e., scheduling, control of power systems, renewable energy system), image processing, and other applications.

SSA is a very promising and interesting algorithm that has already been successfully applied to several problems. SSA shares some advantages with other optimization algorithms (i.e., CSA, BA, and FA), such as simplicity, speed in searching, and ease of hybridization with other optimization algorithms. Furthermore, it has a unique advantage which it has only one parameter (r_1) responsible for balancing between exploration and exploitation [100, 101]. However, SSA suffers from the problem of the slow convergence [38]

Based on the above discussion, SSA is strongly viable for continued employment in the community. This review paper guides researchers who have a present work or planing to work in this field by explaining how SSA can be used to deal with the various problems, pointing out its features and weaknesses, and proving its performance. Thus, different research problems can be solved by using SSA.

Compliance with ethical standards

Conflict of interest The authors declare that there is no conflict of interest regarding the publication of this paper.

References

1. Shehab M, Khader AT, Al-Betar MA (2017) A survey on applications and variants of the cuckoo search algorithm. Appl Soft Comput 61:1041–1059
2. Hazir E, Erdinler ES, Koc KH (2018) Optimization of CNC cutting parameters using design of experiment (DOE) and desirability function. J For Res 29:1423–1434
3. Abualigah LM, Khader AT (2017) Unsupervised text feature selection technique based on hybrid particle swarm optimization algorithm with genetic operators for the text clustering. J Supercomput 73:4773–4795
4. Abualigah LMQ, Hanandeh ES (2015) Applying genetic algorithms to information retrieval using vector space model. Int J Comput Sci Eng Appl 5:19
5. Abualigah LM, Khader AT, Hanandeh ES (2018) Hybrid clustering analysis using improved Krill herd algorithm. Appl Intell 48:4047–4071
6. Abualigah LM, Khader AT, Hanandeh ES (2018) A combination of objective functions and hybrid Krill herd algorithm for text document clustering analysis. Eng Appl Artif Intell 73:111–125
7. Kirkpatrick S (1984) Optimization by simulated annealing: quantitative studies. J Stat Phys 34:975–986
8. Abualigah LM, Khader AT, Hanandeh ES (2018) A novel weighting scheme applied to improve the text document clustering techniques. In: Zelinka I, Vasant P, Duy VH, Dao TT (eds) Innovative computing, optimization and its applications. Springer, Berlin, pp 305–320
9. Glover F (1989) Tabu search—part I. ORSA J Comput 1:190–206
10. Abualigah LM, Sawaie AM, Khader AT, Rashaideh H, Al-Betar MA, Shehab M (2017) β-Hill climbing technique for the text document clustering. New Trends in Information Technology (NTIT)-2017 60
11. Koza JR, Koza JR (1992) Genetic programming: on the programming of computers by means of natural selection, vol 1. MIT Press, Berlin

12. Rajabioun R (2011) Cuckoo optimization algorithm. Appl. Soft Comput 11:5508–5518
13. Yang X-S (2010) Firefly algorithm, stochastic test functions and design optimisation. Preprint arXiv:1003.1409
14. Dorigo M, Di Caro G (1999) Ant colony optimization: a new meta-heuristic. In: Proceedings of the 1999 congress on evolutionary computation-CEC99 (Cat. No. 99TH8406), vol 2. IEEE, New York, pp 1470–1477
15. Geem ZW, Kim JH, Loganathan GV (2001) A new heuristic optimization algorithm: harmony search. Simulation 76:60–68
16. Yang X-S (2010) A new metaheuristic bat-inspired algorithm. In: Pelta DA, Krasnogor N, Dumitrescu D, Chira C, Lung R (eds) Nature inspired cooperative strategies for optimization (NICSO 2010). Springer, Berlin, pp 65–74
17. Bolaji AL, Al-Betar MA, Awadallah MA, Khader AT, Abualigah LM (2016) A comprehensive review: Krill herd algorithm (KH) and its applications. Appl Soft Comput 49:437–446
18. Cheng M-Y, Prayogo D (2014) Symbiotic organisms search: a new metaheuristic optimization algorithm. Comput Struct 139:98–112
19. Mirjalili S (2016) Dragonfly algorithm: a new meta-heuristic optimization technique for solving single-objective, discrete, and multi-objective problems. Neural Comput Appl 27:1053–1073
20. Yang X-S, Deb S (2009) Cuckoo search via lévy flights. In: 2009 World congress on nature and biologically inspired computing (NaBIC). IEEE, New York, pp 210–214
21. Karaboga D (2005) An idea based on honey bee swarm for numerical optimization. Technical report-tr06, Erciyes University, Engineering Faculty, Computer
22. Yang X-S (2012) Flower pollination algorithm for global optimization. In: International conference on unconventional computing and natural computation. Springer, Berlin, pp 240–249
23. Mirjalili S (2015) Moth-flame optimization algorithm: a novel nature-inspired heuristic paradigm. Knowl Based Syst 89:228–249
24. Niu B, Wang H (2012) Bacterial colony optimization. Discrete Dyn Nat Soc 2012:28
25. Simon D (2008) Biogeography-based optimization. IEEE Trans Evol Comput 12:702–713
26. Mirjalili S, Mirjalili SM, Lewis A (2014) Grey wolf optimizer. Adv Eng Softw 69:46–61
27. Mirjalili S (2015) The ant lion optimizer. Adv Eng Softw 83:80–98
28. Eberhart R, Kennedy J (1995) A new optimizer using particle swarm theory. In: MHS'95. Proceedings of the 6th international symposium on micro machine and human science. IEEE, New York, pp 39–43
29. Dhiman G, Kumar V (2017) Spotted hyena optimizer: a novel bio-inspired based metaheuristic technique for engineering applications. Adv Eng Softw 114:48–70
30. Henschke N, Everett JD, Doblin MA, Pitt KA, Richardson AJ, Suthers IM (2014) Demography and interannual variability of salp swarms (thalia democratica). Mar Biol 161:149–163
31. McCauley DJ, Pinsky ML, Palumbi SR, Estes JA, Joyce FH, Warner RR (2015) Marine defaunation: animal loss in the global ocean. Science 347:1255641
32. Shehab M, Khader AT, Al-Betar M (2016) New selection schemes for particle swarm optimization. IEEJ Trans Electron Inf Syst 136:1706–1711
33. Mirjalili S, Gandomi AH, Mirjalili SZ, Saremi S, Faris H, Mirjalili SM (2017) Salp swarm algorithm: a bio-inspired optimizer for engineering design problems. Adv Eng Softw 114:163–191
34. Zhang J, Wang Z, Luo X (2018) Parameter estimation for soil water retention curve using the salp swarm algorithm. Water 10:815
35. Shehab M, Khader AT, Laouchedi M (2017) Modified cuckoo search algorithm for solving global optimization problems. In: International conference of reliable information and communication technology. Springer, Berlin, pp 561–570
36. Shehab M, Khader AT, Laouchedi M, Alomari OA (2018) Hybridizing cuckoo search algorithm with bat algorithm for global numerical optimization. J Supercomput 75:1–28
37. Shehab M, Khader AT, Laouchedi M (2018) A hybrid method based on cuckoo search algorithm for global optimization problems. J ICT 17:469–491
38. Ibrahim RA, Ewees AA, Oliva D, Elaziz MA, Lu S (2018) Improved salp swarm algorithm based on particle swarm optimization for feature selection. J Ambient Intell Humaniz Comput 10:1–15
39. Abusnaina AA, Ahmad S, Jarrar R, Mafarja M (2018) Training neural networks using salp swarm algorithm for pattern classification. In: Proceedings of the 2nd international conference on future networks and distributed systems. ACM, New York, p 17
40. Abualigah LM, Khader AT, Hanandeh ES (2018) A new feature selection method to improve the document clustering using particle swarm optimization algorithm. J Comput Sci 25:456–466
41. Rizk-Allah RM, Hassanien AE, Elhoseny M, Gunasekaran M (2018) A new binary salp swarm algorithm: development and application for optimization tasks. Neural Comput Appl 31:1–23
42. Faris H, Mafarja MM, Heidari AA, Aljarah I, Ala'M A-Z, Mirjalili S, Fujita H (2018) An efficient binary salp swarm algorithm with crossover scheme for feature selection problems. Knowl Based Syst 154:43–67
43. Aljarah I, Mafarja M, Heidari AA, Faris H, Zhang Y, Mirjalili S (2018) Asynchronous accelerating multi-leader salp chains for feature selection. Appl Soft Comput 71:964–979
44. Abualigah LM, Khader AT, Hanandeh ES, Gandomi AH (2017) A novel hybridization strategy for Krill herd algorithm applied to clustering techniques. Appl Soft Comput 60:423–435
45. Wang D, Zhou Y, Jiang S, Liu X (2018) A simplex method-based salp swarm algorithm for numerical and engineering optimization. In: International conference on intelligent information processing. Springer, Berlin, pp 150–159
46. Hegazy AE, Makhlouf M, El-Tawel GS (2018) Improved salp swarm algorithm for feature selection. J King Saud Univ Comput Inf Sci. https://doi.org/10.1016/j.jksuci.2018.06.003
47. Sahu PC, Mishra S, Prusty RC, Panda S (2018) Improved-salp swarm optimized type-II fuzzy controller in load frequency control of multi area islanded AC microgrid. Sustain Energy Grids Netw 16:380–392
48. Yang B, Zhong L, Zhang X, Shu H, Yu T, Li H, Jiang L, Sun L (2019) Novel bio-inspired memetic salp swarm algorithm and application to MPPT for PV systems considering partial shading condition. J Clean Product 215:1203–1222
49. Sun Z-X, Hu R, Qian B, Liu B, Che G-L (2018) Salp swarm algorithm based on blocks on critical path for reentrant job shop scheduling problems. In: International conference on intelligent computing. Springer, Berlin, pp 638–648
50. Patnana N, Pattnaik S, Singh V (2018) Salp swarm optimization based PID controller tuning for doha reverse osmosis desalination plant. Int J Pure Appl Math 119:12707–12720
51. Baygi SMH, Karsaz A, Elahi A (2018) A hybrid optimal PID-fuzzy control design for seismic exited structural system against earthquake: a salp swarm algorithm. In: 2018 6th Iranian joint congress on fuzzy and intelligent systems (CFIS). IEEE, New York, pp 220–225

52. Baygi SMH, Karsaz A (2018) A hybrid optimal PID-LQR control of structural system: a case study of salp swarm optimization. In: 2018 3rd conference on swarm intelligence and evolutionary computation (CSIEC). IEEE, New York, pp 1–6
53. Singh N, Chiclana F, Magnot J-P et al (2019) A new fusion of salp swarm with sine cosine for optimization of non-linear functions. Eng Comput. https://doi.org/10.1007/s00366-018-00696-8
54. Wang J, Gao Y, Chen X (2018) A novel hybrid interval prediction approach based on modified lower upper bound estimation in combination with multi-objective salp swarm algorithm for short-term load forecasting. Energies 11:1561
55. Khamees M, Albakry A, Shaker K (2018) Multi-objective feature selection: hybrid of salp swarm and simulated annealing approach. In: International conference on new trends in information and communications technology applications. Springer, Berlin, pp 129–142
56. Shehab M, Khader AT, Al-Betar MA, Abualigah LM (2017) Hybridizing cuckoo search algorithm with hill climbing for numerical optimization problems. In: 2017 8th international conference on information technology (ICIT). IEEE, New York, pp 36–43
57. Asaithambi S, Rajappa M (2018) Swarm intelligence-based approach for optimal design of cmos differential amplifier and comparator circuit using a hybrid salp swarm algorithm. Rev Sci Instrum 89:054702
58. Sayed GI, Khoriba G, Haggag MH (2018) A novel chaotic salp swarm algorithm for global optimization and feature selection. Appl Intell 48:3462–3481
59. Ahmed S, Mafarja M, Faris H, Aljarah I (2018) Feature selection using salp swarm algorithm with chaos. In: Proceedings of the 2nd international conference on intelligent systems, metaheuristics and swarm intelligence. ACM, New York, pp 65–69
60. Meraihi Y, Ramdane-Cherif A, Mahseur M, Achelia D (2018) A chaotic binary salp swarm algorithm for solving the graph coloring problem. In: International symposium on modelling and implementation of complex systems. Springer, Berlin, pp 106–118
61. Ateya AA, Muthanna A, Vybornova A, Algarni AD, Abuarqoub A, Koucheryavy Y, Koucheryavy A (2019) Chaotic salp swarm algorithm for sdn multi-controller networks. Eng Sci Technol Int J. https://doi.org/10.1016/j.jestch.2018.12.015
62. Hegazy AE, Makhlouf M, El-Tawel GS (2018) Feature selection using chaotic salp swarm algorithm for data classification. Arab J Sci Eng 44:1–16
63. Song M, Chen D (2018) An improved knowledge-informed NSGA-II for multi-objective land allocation (MOLA). Geospat Inf Sci 21:273–287
64. Abualigah LM, Khader AT, Al-Betar MA (2016) Multi-objectives-based text clustering technique using K-mean algorithm. In: 2016 7th international conference on computer science and information technology (CSIT). IEEE, New York, pp 1–6
65. Tolba M, Rezk H, Diab A, Al-Dhaifallah M (2018) A novel robust methodology based salp swarm algorithm for allocation and capacity of renewable distributed generators on distribution grids. Energies 11:2556
66. Jiang P, Li R, Li H (2019) Multi-objective algorithm for the design of prediction intervals for wind power forecasting model. Appl Math Model 67:101–122
67. Benmiloud O, Arif S (2018) Optimal dynamic equivalence based on multi-objective formulation. In: 2018 international conference on electrical sciences and technologies in maghreb (CISTEM). IEEE, New York, pp 1–6
68. Yousri D, AbdelAty AM, Said LA, Elwakil A, Maundy B, Radwan AG (2019) Parameter identification of fractional-order chaotic systems using different meta-heuristic optimization algorithms. Nonlinear Dyn 95:1–52
69. Hao Y, Tian C (2019) The study and application of a novel hybrid system for air quality early-warning. Appl Soft Comput 74:729–746
70. Abbassi R, Abbassi A, Heidari AA, Mirjalili S (2019) An efficient salp swarm-inspired algorithm for parameters identification of photovoltaic cell models. Energy Convers Manag 179:362–372
71. Baliarsingh SK, Vipsita S, Muhammad K, Dash B, Bakshi S (2019) Analysis of high-dimensional genomic data employing a novel bio-inspired algorithm. Appl Soft Comput 77:520–532
72. El-Fergany AA (2018) Extracting optimal parameters of pem fuel cells using salp swarm optimizer. Renew Energy 119:641–648
73. Ekinci S, Hekimoglu B (2018) Parameter optimization of power system stabilizer via salp swarm algorithm. In: 2018 5th international conference on electrical and electronic engineering (ICEEE). IEEE, New York, pp 143–147
74. Papadopoulos TA, Ceylan O, Papagiannis GK (2018) Two-layer earth structure parameter estimation and seasonal analysis. In: 2018 53rd international universities power engineering conference (UPEC). IEEE, New York, pp 1–6
75. Abualigah LMQ (2019) Feature selection and enhanced Krill herd algorithm for text document clustering. Springer, Berlin
76. Ibrahim HT, Mazher WJ, Ucan ON, Bayat O (2017) Feature selection using salp swarm algorithm for real biomedical datasets. Int J Comput Sci Netw Secur 12:13
77. Zhang J, Teng Y-F, Chen W (2018) Support vector regression with modified firefly algorithm for stock price forecasting. Appl Intell 49:1–17
78. Hussien AG, Hassanien AE, Houssein EH (2017) Swarming behaviour of salps algorithm for predicting chemical compound activities. In: 2017 8th international conference on intelligent computing and information systems (ICICIS). IEEE, New York, pp 315–320
79. Zhang X, Wang J, Liu Z, Wang J (2019) Weak feature enhancement in machinery fault diagnosis using empirical wavelet transform and an improved adaptive bistable stochastic resonance. ISA Trans 84:283–295
80. Esfe MH, Ahangar MRH, Rejvani M, Toghraie D, Hajmohammad MH (2016) Designing an artificial neural network to predict dynamic viscosity of aqueous nanofluid of TiO_2 using experimental data. Int Commun Heat Mass Transf 75:192–196
81. Bairathi D, Gopalani D (2019) Salp swarm algorithm (SSA) for training feed-forward neural networks. In: Bansal JC, Das KN, Nagar A, Deep K, Ojha AK (eds) Soft computing for problem solving. Springer, Berlin, pp 521–534
82. Kouba NEY, Boudour M (2019) A brief review and comparative study of nature-inspired optimization algorithms applied to power system control. In: Li X, Wong KC (eds) Natural computing for unsupervised learning. Springer, Berlin, pp 35–49
83. Mohapatra TK, Sahu BK (2018) Design and implementation of SSA based fractional order PID controller for automatic generation control of a multi-area, multi-source interconnected power system. In: 2018 Technologies for smart-city energy security and power (ICSESP). IEEE, New York, pp 1–6
84. Sahu PC, Prusty RC, Panda S (2018) Salp swarm optimized multistage PDF plus $(1 + \mathrm{PI})$ controller in agc of multi source based nonlinear power system. In: International conference on soft computing systems. Springer, Berlin, pp 789–800
85. El-Fergany AA, Hasanien HM (2019) Salp swarm optimizer to solve optimal power flow comprising voltage stability analysis. Neural Comput Appl. https://doi.org/10.1007/s00521-019-04029-8

86. Guha D, Roy P, Banerjee S (2018) A maiden application of salp swarm algorithm optimized cascade tilt-integral-derivative controller for load frequency control of power systems. IET Gener Transm Distrib 9:25–36
87. Kuyu YC, Vatansever F (2018) Real loss minimization in power systems via recent optimization techniques. In: 2018 2nd international symposium on multidisciplinary studies and innovative technologies (ISMSIT). IEEE, New York, pp 1–4
88. Rezk H, Fathy A (2017) A novel optimal parameters identification of triple-junction solar cell based on a recently meta-heuristic water cycle algorithm. Sol Energy 157:778–791
89. Mohamed MA, Diab AAZ, Rezk H (2019) Partial shading mitigation of pv systems via different meta-heuristic techniques. Renew Energy 130:1159–1175
90. Barik AK, Das DC (2018) Active power management of isolated renewable microgrid generating power from rooftop solar arrays, sewage waters and solid urban wastes of a smart city using salp swarm algorithm. In: 2018 technologies for smart-city energy security and power (ICSESP). IEEE, New York, pp 1–6
91. Chang Z, Cao J, Zhang Y (2018) A novel image segmentation approach for wood plate surface defect classification through convex optimization. J For Res 29:1789–1795
92. Dhal KG, Ray S, Das A, Das S (2018) A survey on nature-inspired optimization algorithms and their application in image enhancement domain. Arch Comput Methods Eng 26:1–32
93. Ibrahim A, Ahmed A, Hussein S, Hassanien AE (2018) Fish image segmentation using salp swarm algorithm. In: International conference on advanced machine learning technologies and applications. Springer, Berlin, pp 42–51
94. Liu X, Xu H (2018) Application on target localization based on salp swarm algorithm. In: 2018 37th Chinese control conference (CCC). IEEE, New York, pp 4542–4545
95. Khalid A, Javaid N, Mateen A, Ilahi M, Saba T, Rehman A (2019) Enhanced time-of-use electricity price rate using game theory. Electronics 8:48
96. Khalid A, Khan ZA, Javaid N (2018) Game theory based electric price tariff and salp swarm algorithm for demand side management. In: 2018 5th HCT information technology trends (ITT). IEEE, New York, pp 99–103
97. Erdoğmuş P (2018) Nature inspired optimization algorithms and their performance on the solution of nonlinear equation systems. Sakarya Univ J Comput Inf Sci 1:44–57
98. Asasi MS, Ahanch M, Holari YT (2018) Optimal allocation of distributed generations and shunt capacitors using salp swarm algorithm. In: Iranian conference on electrical engineering (ICEE). IEEE, New York, pp 1166–1172
99. Sereshki AB, Derakhshani A (2018) Optimizing the mechanical stabilization of earth walls with metal strips: applications of swarm algorithms. Arab J Sci Eng 44:1–14
100. Qais MH, Hasanien HM, Alghuwainem S (2019) Enhanced salp swarm algorithm: application to variable speed wind generators. Eng Appl Artif Intell 80:82–96
101. Moth–flame optimization algorithm: variants and applications