Solving optimization problems is an ever-growing subject with an enormous number of algorithms. Examples of such algorithms are Scatter Search (SS) and genetic algorithms. Modifying and improving of algorithms can be done by adding diversity and guidance to them. Chaotic maps are quite sensitive to the initial point, which means even a very slight change in the value of the initial point would result in a dramatic change of the sequence produced by the chaotic map Arnold's Cat Map. Arnold's Cat Map is a chaotic map technique that provides long non-repetitive random-like sequences.

Chaotic maps play an important role in improving evolutionary optimization algorithms and meta-heuristics by avoiding local optima and speeding up the convergence. This paper proposes an implementation of the scatter search algorithm with travelling salesman as a case study, then implements and compares the developed hyper Scatter Arnold's Cat Map Search (SACMS) method against the traditional Scatter Search Algorithm. SACMS is a hyper Scatter Search Algorithm with Arnold's Cat Map Chaotic Algorithm. Scatter Arnold's Cat Map Search shows promising results by decreasing the number of iterations required by the Scatter Search Algorithm to get an optimal solution(s). Travelling Salesman Problem, which is a popular and well-known optimization example, is implemented in this paper to demonstrate the results of the modified algorithm Scatter Arnold's Cat Map Search (SACMS). Implementation of both algorithms is done with the same parameters: population size, number of cities, maximum number of iterations, reference set size, etc. The results show improvement by the modified algorithm in terms of the number of iterations required by SS with an iteration reduction of 10–46 % and improvements in time to obtain solutions with 65 % time reduction

Keywords: scatter search, Arnold's cat map, chaotic, TSP, metaheuristic, optimization problems

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DEVELOPMENT OF AN ENHANCED SCATTER SEARCH ALGORITHM USING DISCRETE CHAOTIC ARNOLD'S CAT MAP

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1. Introduction

Many complex optimization problems can be solved with many variables exactly over a very limited time for calculations. This causes great interest in search algorithms, which find optimal solutions at reasonable times of work. One of these optimal problems is the Travelling Salesman Problem (TSP). TSP is looking for the shortest path to visit the city group and return to the starting point. Even though the problem statement is quite simple, it's a problem of improving a well-known complex NP constraint that can be solved in a time limit. Currently, TSP is thoroughly studied and resolved using various top-end approaches, like research typography, evolutionary algorithms, neural networks, bee algorithm and ant colony system [1].

Values of random variables are commonly used in the field of artificial intelligence. The chaotic methods of generating random variables are concerned with mainly continuous random variables [2]. Many algorithms and calculation methods are based on random values. However, the use of these methods is not always profitable, because of costs or time required for generating these numbers. In case of the above-mentioned situations, we can apply pseudo-random values, which are using computers to generate them.

2. Literature review and problem statement

The literature provides methods for continuous and discrete distributions. Algorithms and methods from the first group may be used in artificial intelligence algorithms [3, 4]. The other group of algorithms is used especially for data encryption, for example, stream ciphers [5, 6]. Therefore, the discrete values are often connected with binary values generation based on a uniform distribution. In this case, the obtained values have to be of appropriate quality, which means they have to pass many statistical tests [7, 8] Also, discrete pseudorandom numbers may be used in other applications, for example, computer games, in which data processing forms other probability distributions. Some of the methods used for making pseudo-random values are based on chaotic mappings. The reason is connected with the properties of chaotic systems (such as behavior resembling randomness) and the deterministic way in which values are obtained [2].

Most of the traditional algorithms are problem-specific, which is one of the important limitations, whereas, metaheuristic algorithms may be applied to numerous problems. To solve these problems, various metaheuristic algorithms, namely Ant colony optimization (ACO), Genetic algorithms (GAs), Artificial bee colony algorithm (ABC) and Harmony search algorithm (HS), have been experimented by researchers [9].

Scatter search can be defined as a meta-heuristic algorithm and global optimization. Sometimes it is also related to the evolutionary algorithms due to using the population and re-combination technical structure [10]. Using greatly enhanced ability to optimize relevant solutions within a reasonable time period using a metaheuristic [11].

The paper [11] proposes an alternative, hybrid algorithm by combining two metaheuristics: ant colony optimization (ACO) and simulated annealing (SA), in order to find near-optimal solutions in a reasonable time. It develops a parallel implementation of our hybrid approach on graphics processing units using CUDA. It shows that the hybrid metaheuristic approach yields almost optimal solutions, while computing them significantly faster than when using branch-and-bound. The paper [12] has suggested a dynamic SS algorithm for solving the TSP problem. The suggested SS algorithm has resulted in improving the quality of the solution in standard test cities, however, with higher time consumption. The paper [13] suggested an improved SS by increasing algorithm diversity through bees algorithm. The paper [14] gives a hybrid method based on diffusion studies of scatter search with TABU search, applying restriction to the search space solutions through Ejection Chain mechanism, which provides a parallel design to run in a Graphics Processing Unit (GPU). The paper [15] presented a two-stage model to achieve real-time object images, biometric images and medical images encoding. In the first stage of this model, the chaotic map is defined. In the second stage, the encoding is performed using series of transformation operations, including phase transformation, radical transformation and bit adaptive transformation. The paper [16] implements with Matlab a 2D designed simulation of cat mat, then uses it as a 1D sequence encryption generator while doing a throughout study of the statistical properties and its dynamics provided by the simulation. The paper [17] presents a modified scatter search algorithm (MSSA) to reinforce the ordinary scatter search algorithm (SSA) to be equipped for handling large-scale transmission expansion planning (TEP) problems. It incorporates some improved strategies so as to decrease the number of linear programming problems required to be solved iteratively. In this study, it is shown that the MSSA can handle TEP problems faster than the ordinary SSA.

3. The aim and objectives of the study

The aim of the study is to implement an algorithm that finds an optimal solution to the travelling salesman problem with a minimum number of iterations required and time.

To achieve this aim, the following objectives are accomplished:

– implementing the traditional Scatter Search Algorithm to solve TSP;

– proposing and implementing SACMS, which is a hybrid algorithm integrating the guiding of ACM, which provides long non-repetitive random-like sequences into scatter search algorithm;

– comparing the results of implementing the above two algorithms solving the TSP using the same parameters.

4. Materials and methods

4. 1. Theoretical background of scatter search algorithm SS

The aim of the Scatter Search is maintaining a group of various and high-quality candidate solution cases. The concept of this method is that the beneficial information on global optima is maintained in an elite and diverse solution set (i.e. reference set) and that re-combining samples from the group may benefit from that information. The strategy includes an iterative procedure, in which a population of high-quality and diverse candidate solutions, which have been divided into sub-sets and linearly re-combined for the creation of the weighted sample-based neighborhood centroids. The re-combination results have been refined with the use of an embedded heuristic and evaluated in a context of reference set as to whether they are retained or not [2, 17].

The SS operated on a population of the problem solutions, which need to be solved, stored in a group of the solutions that have been referred to as Reference Set. The solutions in that set have been combined for the purpose of obtaining new solutions, attempting at the generation of more sufficient solutions every time, based on the criteria of diversity and high quality. The basic SS algorithm design is based, in general, on the 5 steps below [18]:

– an approach of Improvement for the transformation of a trial solution to one or several improved trial solutions;

– an approach of Diversification Generation, which is utilized for generating a *P* of various trial solutions in the search space;

– an approach of the Reference Set Updates for building and maintaining a Reference Set (RefSet). The aim is ensuring diversity with the simultaneous maintenance of high-quality solutions. For example, one may choose the RefSet-1 solutions with the best objective function and after that, adding RefSet-2 solutions with optimal diversity solutions (RefSet = RefSet 1+RefSet 2);

– an approach of Solution Combination for transforming a certain sub-set of the solutions that are produced by an approach of Sub-set Generation to one or several combined solution vectors;

– an approach of Sub-set Generation for operating on the RefSet, for the production of numerous sub-sets of its solutions as a base for the creation of the combined solutions.

Fig. 1 shows the 4 steps of SS.

The combined solutions produce new solutions and those new solutions' fitness will be assessed. The new solutions that will be subjected to RefSet update approach are [17]:

1) the new solution is of a superior value of the objective function compared to the solution with the worst objective value in the RefSet-1;

2) the new solution is of a better diversity value compared to the solution with the worst diversity value in RefSet-2;

The search continues while the Reference Set has been changed. In the case where there aren't any changes in the Reference Set, the algorithm checks if the number of iterations (itr) reaches the max iteration (MaxItre), which has been detected by the user. In this case, this algorithm will show the good solution (or solutions) reached, otherwise, the new P will be produced and the Ref-Set1 will be added to the start of the new value of P [17].

Algorithm 1: Scatter Search
Input: P=Population, *Maxitr*.
Output: Best solution found.
Initialize the population (P) with the use of an approach of Diversification Generation;
Applying the Improvement approach to P;
Reference Set Update Approach (Good solutions for *RefSet1* and Diversity solutions for *RefSet2*);
While (*itr* < *Maxitr*) do
Subset Generation Method;
While (subset-counter < > 0) do
Solution Combination Method;
Improvement Method;
Reference Set Update Method;
End while
End while

Fig. 1. Scatter Search Algorithm

4. 2. Theoretical background of Arnold's cat map

Arnold's Cat Map (ACM) can be defined as a chaotic map from torus into itself, named after V. Arnold, who has shown its effects in the 1960s with the use of a cat image; hence its name. The dynamics of any system is described by a mathematical model that reflects the dependencies between input, output, and state variables. ACM is a special two-dimensional chaotic map [19–21].

For defining Arnold's cat map, it is first necessary to define a torus and phase space. A torus can be described as the surface, which is obtained from revolving a circle in a 3-D space that surrounds a disconnected axis, which is coplanar with that circle. A phase space is a representation of all the potential system states, and each of the states corresponds to a single unique point. The map may be characterized as a discrete system where trajectories in the phase space are stretched and folded for obtaining a torus. The mathematical ACM definition can be seen in Equation 1 [18].

Let $X=[x\ y]$. X is an $n\times n$ matrix, and Arnold's cat map transformation is as follows [18]:

$$\Gamma\colon [x\ y]\to[1\ 1\ 1\ 2]\ [x\ y] \bmod n= \\ =[1\ 0\ 1\ 1]\ [1\ 1\ 0\ 1]\ [x\ y] \bmod n. \tag{1}$$

Due to the fact that this is a chaotic map, which is made up of a discrete system, it expresses the dynamics of chaos. The initial conditions will impact the map, and its outputs will seem arbitrary [22].

4. 3. Proposed algorithm: scatter Arnold's cat map search SACMS

Combination and Improvement steps in SS are very fundamental and crucial to the solution of optimization problems. Selecting the solutions to be combined usually is carried out by determining the higher-ranked solutions then combining. Applying guidance with a chaotic method such as Arnold's cat map increases the chances of reaching the goal faster with good optimal or near-optimal solutions by adding randomness to escape the situation of a local optimum. An effective model provides accurate results with small deviations over a long period. Input x, output y, and state must be present in any system modeling dynamic processes. Many models provide high results, but only for a short time. Others succeed only in the presence of a very limited set of initial assumptions, which may be a pure coincidence of circumstances. A model that deserves serious attention must be sustainable in the sense that it provides equally good results under different conditions and for different periods. The algorithm after modification is shown in Fig. 2.

Algorithm 2 (proposed algorithm): Scatter Arnold's Cat Map Search
Input: P=Population, *Maxitr*.
Output: Optimal solution found.
Initializing population (P) with the use of an approach of Diversification Generation;
Applying the approach of Improvement to P;
Reference Set Update Approach (Good solutions for the *RefSet1* and Diversity solutions for the *RefSet2*);
While (*itr* < *Maxitr*) do
Sub-set Generation Approach;
While (sub-set-counter < > 0) do
Guide Solution Combination approach by Arnold's Cat Map;
Improvement Approach;
Reference Set Update Approach;
End while
End while

Fig. 2. Scatter Arnold's Cat Map Search SACMS

Parameters used in the above algorithm are as follows:

– P represents the size of the population (number of solutions generated in the algorithm);

– *Maxitr* is the maximum number of iterations;

– Reference Set is the set of best solution candidates for improvements;

– *RefSet*1 is the best objective function solutions;

– *RefSet*2 is Diversity solutions;

– *Itr* is the current iteration number.

4. 4. Case study: travelling salesman problem (TSP)

The case study used is the travelling salesman problem. TSP is a major success story of optimization because of its simplicity and applicability (or perhaps simply because of its interesting name). For many years, the TSP has played the role of an initial proving ground for the new ideas that are associated with those two alternatives. Those new ideas make the TSP an optimal subject for the case study [23–25].

The Travelling Salesman Problem (TSP) origins are rather mysterious. It is one of the conventional combinatorial optimization problems and may be described as a salesman who must visit the clients in various cities, needs to find the shortest route beginning from his home city, then visit each one of the cities exactly once and ending back at the starting point. In a more formal way, the problem can be stated as follows [24].

Considering a group of n nodes and costs that are related to every pair of nodes, finding a closed tour of the minimum total cost, containing each one of the nodes precisely once, i.e., a set $\{c1, c2,..., cN\}$ of cities is given and for each of the pairs $\{ci, cj\}$ of distinct cities a distance $d(ci, cj)$. The aim is finding an ordering Π of cities minimizing the quantity by the use of (2):

$$\sum^{N-1} d\left(c\Pi(i), c\Pi(i+1)\right) + d\left(c\Pi(N), c\Pi(1)\right) i=1. \tag{2}$$

This quantity has been known as the length of the tour, due to the fact that it is the tour length a salesman would make in case of visiting cities by the order that has been given by permutation, ending up in the city he started in. The focus in the present paper is on symmetric TSP, where distance values satisfy [24]:

$$d(ci,cj)=d(cj,ci) \text{ for } 1\le i,j\le N. \quad (3)$$

Since the objective of the travelling salesman is to minimize distance or cost based on (2) and (3), the travelling salesman is considered a minimization optimal.

5. Results of development of an enhanced scatter search algorithm

5. 1. Results for implementation of the traditional scatter search algorithm

Scatter Search has been tested using 10 cities TSP and 100 iterations with Initial population $P=100$, Reference Set RefSet=10. Table 1 below shows the results of applying traditional scatter search to TSP.

The proposed method has been implemented in Windows 7 Operating System with Core Due 2 Intel CPU with Visual Basic 6.

Table 1

Scatter Search Results

TSP	Scatter Search		Fitness Function (Optimal)
	Iteration	Time (sec)	
1	28	0.023	90
2	76	0.015	135
3	92	0.023	85
4	68	0.023	55
5	38	0.023	90
6	37	0.023	85
7	81	0.023	30
8	57	0.023	60
9	90	0.023	60
10	71	0.015	50

5. 2. Results for implementation of the proposed scatter Arnold's cat map search SACMS

Scatter Arnold's Cat Map Search has been tested using 10 cities TSP and 100 iterations with Initial population $P=100$, Reference Set RefSet=10. Table 2 below shows the results of applying SACMS to TSP.

Table 2

Scatter Arnold's Cat Map Search Results

TSP	SACMS		Fitness Function (Optimal)
	Iteration	Time (sec)	
1	3	0.015	90
2	15	0.015	135
3	24	0.015	85
4	10	0.023	55
5	10	0.023	90
6	17	0.015	85
7	14	0.015	30
8	15	0.023	60
9	27	0.015	60
10	7	0.015	50

5. 3. Comparing results between the traditional algorithm and the proposed algorithm

To examine the efficiency of the proposed algorithms, we compared SACMS with standard SS as shown in Table 3 with regard to the number of iterations and time measured in seconds. No fitness function values need to be compared since running both algorithms gives the same optimal solution.

Table 3

Comparison of SS and SACMS results

TSP	SS		SACMS		Fitness Function (Optimal)
	Iteration	Time (sec)	Iteration	Time (sec)	
1	28	0.023	3	0.015	90
2	76	0.015	15	0.015	135
3	92	0.023	24	0.015	85
4	68	0.023	10	0.023	55
5	38	0.023	10	0.023	90
6	37	0.023	17	0.015	85
7	81	0.023	14	0.015	30
8	57	0.023	15	0.023	60
9	90	0.023	27	0.015	60
10	71	0.015	7	0.015	50

Fig. 3 below shows a comparison in the number of iterations required to reach the optimal solution by the proposed algorithm SACMS and the number of iterations required by the traditional scatter search algorithm SS.

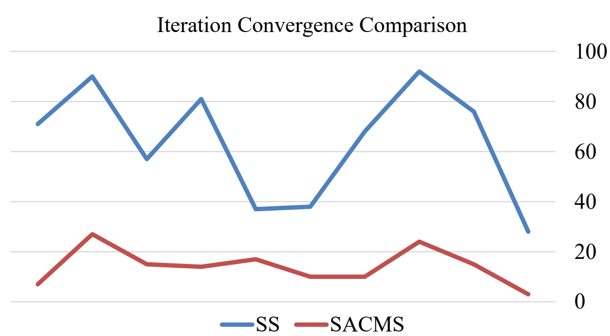

Fig. 3. Comparison of Iteration Convergence

Fig. 4 below shows a comparison in time measured in seconds required to reach the optimal solution by the proposed algorithm SACMS and the time required by the traditional scatter search algorithm SS.

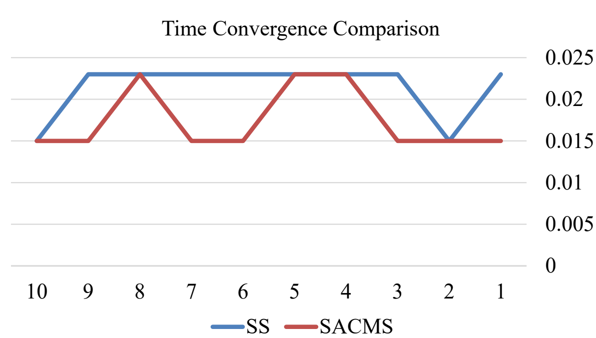

Fig. 4. Comparison of Time Convergence

6. Discussion of experimental results of the traditional algorithm and the proposed algorithm

Arnold's Cat Map is a chaotic map technique that provides long non-repetitive random-like sequences. Chaotic maps play an important role in improving evolutionary optimization algorithms and meta-heuristics by avoiding local optima and speeding up the convergence.

Results in Table 1 above show the time in seconds for applying SS to each TSP with an average time of 0.0214 seconds, even if the number of iterations to reach the optimal solution is varied with average iteration 64.

Results in Table 2 above show the time in seconds for applying SACMS to each TSP with an average time of 0.0174 seconds, even if the number of iterations to reach the optimal solution is varied with average iteration 14.

Examining the results shown in Table 3 indicates a good improvement of SACMS to reach optimal solutions in a smaller number of iterations by reaching solutions with 65 % fewer required iterations. The proposed algorithm provides an improved faster approach with run time reduction lying between 10 % and 46 %. Since ACM provides high-quality diversion in the search space.

Fig. 3 above shows a significant reduction in the number of iterations required to reach the optimal solution by the proposed algorithm SACMS when comparing it to the number of iterations required by the traditional scatter search algorithm SS.

Fig. 4 above shows a significant reduction in time measured in seconds required to reach the optimal solution by the proposed algorithm SACMS when comparing it to the time required by the traditional scatter search algorithm SS.

Since both algorithms depend on randomness, the optimal solution can be reached at similar times even at rare occurrences.

Limitation of the search algorithm and to randomness-based techniques is its dependencies on initial values and sensitiveness to it.

Difficulties that such work methodology can face is the obtaining and normalizing the data of a large number of actual cities datasets.

There are several suggestions for future work as follows:

– more experiments can be carried out by combining another heuristic with both algorithms;

– different TSP scenarios can be implemented and compared;

– results can be compared to several benchmark traditional heuristics and techniques.

7. Conclusions

1. TSP is a benchmark combinatorial optimization problem that can be implemented and provide a good perspective when comparing optimization problems. With scatter search as an optimization problem solving technique that provides optimal solution yet can be further enhanced.

2. SACMS can be considered as computationally fast optimizer tools without any special domain information.

3. Experiments improve that the fitness value for the enhanced and original algorithms has been similar since both are capable optimizers. The time taken by SACMS is less than the time taken by the original SS even if under low conditions (small-sized instance), all the algorithms tested may have similar occasional time performance. The results show improvement by the modified algorithm in terms of the number of iterations required by SS with iteration reduction of 10–46 % and improvements in time to obtain solutions with 65 % time reduction.

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