Tree-seed algorithm in solving real-life optimization problems

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Abstract. Tree-seed algorithm (TSA) is a nature-inspired and population-based algorithm for solving continuous optimization problems. The tree-seed relationship is the main motivation of this algorithm. TSA has only two peculiar parameters which are the total number of trees in the stand (pop) and the controller of the seed production (search tendency). Although many problems have been solved in the literature by TSA which is the successful optimizer for low dimensional unconstrained continuous problems, real-life problems have not been addressed yet. In this study, six continuous unconstrained real-life optimization problems (gas transmission compressor design, optimal capacity of gas production facility, gear train design, frequency modulation sounds parameter identification, the spread spectrum radar polyphase code design with 10 decision variables, the spread spectrum radar polyphase code design with 20 decision variables) have been solved. It is seen that choosing the number of the population as 50 and the value of search tendency as 0.1 is appropriate according to experimental results for these problems.

Keywords: Tree-Seed Algorithm, Real-Life Problems, Optimization, Unconstrained Continuous Problems

1. Introduction

The purpose of optimization is to provide maximum benefit with minimum cost. Optimization problems are solved with exact methods such as Linear Programming and also heuristic methods such as TSA. Due to some optimization problem, NP-Hard problems, cannot be solved in polynomial time, heuristic methods (not always guarantee the optimum but satisfies the near optimum) are proposed so as to solve these kinds of problems. Since 1975, more than 300 metaheuristic algorithms have been proposed for solving optimization problems. One of these methods is TSA proposed by Kiran [1] in 2015. TSA models the relationship between trees and their seeds to solve optimization problems. In TSA, the ground is search space, trees and seeds are potential solutions for the problem. Due to the fact that TSA is a population-based a heuristic algorithm, the information sharing and communication with each other in the population (swarm intelligence) is used in order to create new candidate solutions. Diversification and intensification phases are controlled by ST in the TSA. A random tree is used for seed creation in diversification phase and the best tree for seed creation in intensification phase. Unconstrained continuous optimization problems have been solved by TSA effectively. In literature, various TSA versions can be found for example constrained continuous [2], discrete binary [3] and parallel [4-6]. In this study, real-life optimization problems (ROPs) have been solved via TSA. This is the first study for solving ROPs through TSA. The original TSA is introduced briefly in section 2, the details of the experimental setup are given in section 3, the results and discussion are presented in section 4 and concludes of this paper are given in section 5.

2. Tree-seed algorithm

TSA is a nature-inspired, population-based, stochastic, metaheuristic optimization algorithm in swarm intelligence category. TSA is proposed by Kiran [1] based on the relationship between trees and seeds
for the solving of continuous optimization problems. Seeds are used as reproduction and propagation mechanisms. Seeds are transported in accordance with their structure. Some seeds are carried from tree to different places by holding on to birds 'feathers, animals' furs and clothes. Thus, in the suitable environment seeds grows and becomes a tree. Ground is considered to be the search space of optimization problem. By the way, both of the trees and seeds are considered the solutions of optimization problem. Exploration and exploitation process of the algorithm is so important for the metaheuristic methods to obtain qualified solutions. At the stage of exploration, trees are scattered in the search space randomly, and the seeds of the same characteristics with the trees are used in the exploitation stage. Seed number of each tree is determined randomly, but not less than one. It is recommended that the number of random seeds is between 10% and 25% of the total number of trees. Seeds are derived according to ST used to choose either the best tree or the randomly selected tree during seed creation and using two seed production equation given as follows:

\[ S_{k,j} = T_{i,j} + \alpha_{i,j} x (B_j - T_{r,j}) \]  \hspace{1cm} (1)  
\[ S_{k,j} = T_{i,j} + \alpha_{i,j} x (T_{i,j} - T_{r,j}) \]  \hspace{1cm} (2)

where, \( S_{k,j} \) is \( j \)th dimension of the \( k \)th seed derived from \( i \)th tree , \( T_{i,j} \) is the \( j \)th dimension of \( i \)th tree, \( B_j \) is \( j \)th dimension of achieved best tree location so far, \( T_{r,j} \) is \( j \)th dimension of the \( r \)th tree which is selected randomly in population, \( \alpha_{i,j} \) is scale factor that is randomly generated in the range of [-1,1]. A greedy selection is carried out between the seeds of each tree in the search process and the best seed is determined. If the solution quality of best seed is better than its own tree, the tree dries and the best seed substitutes that tree. TSA algorithm is executed until the termination criteria are met. For detailed information, pseudocode, and flowchart, readers can look at these [1-8] works.

3. Experimental setup

In this study, we used six real world engineering optimization problems (gas transmission compressor design, optimal capacity of gas production facility, gear train design, frequency modulation sounds parameter identification, the spread spectrum radar polyphase code design with 10 decision variables, the spread spectrum radar polyphase code design with 20 decision variables). These problems are unconstrained and highly nonlinear. The maximum function evaluations numbers (maxFEs), dimensions and bounds are shown in Table 1. The Pop is taken as 50 and 100. The ST is taken as 0.1, 0.5 and 0.9.

| No | Problem Name | D | maxFEs (Dx10000) | Bounds |
|----|--------------|---|-----------------|--------|
| F1 | Gas transmission compressor design | 3 | 30000 | 10 ≤ x₁ ≤ 55  
1.1 ≤ x₂ ≤ 2  
10 ≤ x₃ ≤ 40 |
| F2 | Optimal capacity of gas production facility | 2 | 20000 | 17.5 ≤ x₁ ≤ 40  
300 ≤ x₂ ≤ 600 |
| F3 | Gear train design | 4 | 40000 | 12 ≤ xᵢ ≤ 60  
i = 1, 2, 3, 4 |
| F4 | Frequency modulation sounds parameter identification | 6 | 60000 | -6.4 ≤ xᵢ ≤ 6.35  
i = 1, 2, 3, 4, 5, 6 |
| F5 | The spread spectrum radar polyphase code design | 10 | 100000 | 0 ≤ xᵢ ≤ 360  
i = 1, ...,10 |
| F6 | The spread spectrum radar polyphase code design | 20 | 200000 | 0 ≤ xᵢ ≤ 360  
i = 1, ...,20 |
3.1. Gas transmission compressor design problem
The aim of this design problem which has 3 decision variables (x1, x2 and x3) to find the optimal design parameters when 100 million cu. Ft. of gas per day are delivered with minimum cost for a gas pipeline transmission system [9]. x1 is the length between compressor stations (in miles), x2 is the compressor ratio and x3 is the pipe inside diameter (in inches). Mathematical model of Gas Transmission Compressor Design Problem is given as follow (Eq. 3).

\[
\text{Min } F_1(x) = 8.61 \times 10^5 x_1^{1/2} x_2^{2/3} x_3^{-2/3} (x_2^2 - 1)^{-1/2} + 3.69 \times 10^4 x^3 \\
+ 7.72 \times 10^8 x_1^{-1/2} x_2^{0.219} - 765.43 x \times 10^6 x_1^{-1}
\]

3.2. Optimal capacity of gas production facility
The optimum combination of capacities of the production facilities of an oxygen production and inventory system is found in this optimization problem. There are 2 decision variable that need to be optimized. First decision variable x1 is oxygen production rate and second decision variable x2 is oxygen storage pressure. Mathematical model of Optimal Capacity of Gas Production Facility problem is given as follow (Eq. 4).

\[
\text{Min } F_2(x) = 61.8 + 5.72 x_1 + 0.2623 \left[ (40 - x_1) \ln \left( \frac{x_2}{200} \right) \right]^{-0.85} \\
+ 0.087 (40 - x_1) \ln \left( \frac{x_2}{200} \right) + 700.23 x_2^{-0.75}
\]

3.3. Gear train design
In this problem, there are four decision variables (x1 to x4). These decision variables represent the number of teeth in gear which must be an integer and in the range of [12, 58]. Mathematical model of Gear Train Design problem is given as follow (Eq. 5).

\[
\text{Min } F_3(x) = \left[ \frac{1}{6.931} - \frac{x_1 x_2}{x_3 x_4} \right]^2
\]

3.4. Frequency modulation sounds parameter identification
This problem is highly complex multimodal problem, having strong epitasis and have 6 decision variables which is in the bounds of [-6.4, 6.35]. Mathematical model of Frequency Modulation Sounds Parameter Identification problem is given as follow (Eq. 6).

\[
\text{Min } F_4(x) = \sum_{t=0}^{100} \left( (x_1 x \sin(x_2 t x 3.6 + x_3 x \sin(x_4 t x 3.6 + x_5 x \sin(x_6 t x 3.6))) \right) \\
- (1.0 x \sin(5.0 x t x 3.6 + 1.5 x \sin(4.8 x t x 3.6 + 2.0 x \sin(4.9 x t x 3.6 ))))^2
\]

3.5. The spread spectrum radar poly phase code design
This problem is min-max continuous optimization problem and it have a lot of local optimum. The spread spectrum radar polyphase code design problem has 10 (for F5) and 20 (for F6) decision variables. Mathematical model of The Spread Spectrum Radar Poly Phase Code Design problem is given as follow (Eq. 7-8).

\[
\text{Min } F_6(x) = \text{Min } F_5(x)
\]
Min \( F_5(x) = \max \{ f_1(X), \ldots, f_{2m}(X) \} \)

\[
X = \{(x_1, \ldots, x_n) \in \mathbb{R}^n | 0 \leq x_j \leq 2\pi, j = 1, 2, \ldots, n \text{ and } m = 2n - 1\}
\]

\[
f_{2i-1}(x) = \sum_{j=1}^{n} \cos \left( \sum_{k=p_j+1}^{p_{j-1}+1} x_k \right), i = 1, 2, \ldots, n
\]

\[
f_{2i-1}(x) = 0.5 + \sum_{j=i+1}^{n} \cos \left( \sum_{k=p_{j-1}+1}^{p_j-1} x_k \right), i = 1, 2, \ldots, n - 1
\]

\[
f_{m+1}(x) = -f_i(x), i = 1, 2, \ldots, m
\]

The mathematical models of these problems are presented in Eq.3-8. The gas transmission compressor design problem has 3 decision variables. The optimal capacity of gas production facility problem has 2 decision variables. The gear train design problem has 4 decision variables. The frequency modulation sounds parameter identification problem has 6 decision variables.

### 4. Results and discussion

Six unrestricted real-world optimization problems were solved by TSA and the results were shown in the following tables. For each optimization problem, population value was changed from 50 to 100 and ST value was changed to 0.1, 0.5, 0.9 respectively and its effect on the quality of the solution was investigated.

**Table 2. The peculiar parameters analysis for F1 problem**

| F1          | Mean       | Std.Dev.   | Median | Min    | Max    |
|-------------|------------|------------|--------|--------|--------|
| Pop=50 ST=0.1 | 2.9644E+06 | 1.4209E-09 | 2.9644E+06 | 2.9644E+06 | 2.9644E+06 |
| Pop=50 ST=0.5 | 2.9644E+06 | 7.6369E-10 | 2.9644E+06 | 2.9644E+06 | 2.9644E+06 |
| Pop=50 ST=0.9 | 2.9644E+06 | 2.3964E-09 | 2.9644E+06 | 2.9644E+06 | 2.9644E+06 |
| Pop=100 ST=0.1 | 2.9644E+06 | 3.2281E-06 | 2.9644E+06 | 2.9644E+06 | 2.9644E+06 |
| Pop=100 ST=0.5 | 2.9644E+06 | 9.0824E-05 | 2.9644E+06 | 2.9644E+06 | 2.9644E+06 |
| Pop=100 ST=0.9 | 2.9644E+06 | 1.5505E-03 | 2.9644E+06 | 2.9644E+06 | 2.9644E+06 |

**Table 3. The peculiar parameters analysis for F2 problem**

| F2          | Mean       | Std.Dev.   | Median | Min    | Max    |
|-------------|------------|------------|--------|--------|--------|
| Pop=50 ST=0.1 | 1.6984E+02 | 1.4454E-13 | 1.6984E+02 | 1.6984E+02 | 1.6984E+02 |
| Pop=50 ST=0.5 | 1.6984E+02 | 1.4454E-13 | 1.6984E+02 | 1.6984E+02 | 1.6984E+02 |
| Pop=50 ST=0.9 | 1.6984E+02 | 1.4454E-13 | 1.6984E+02 | 1.6984E+02 | 1.6984E+02 |
| Pop=100 ST=0.1 | 1.6984E+02 | 1.4454E-13 | 1.6984E+02 | 1.6984E+02 | 1.6984E+02 |
| Pop=100 ST=0.5 | 1.6984E+02 | 1.4454E-13 | 1.6984E+02 | 1.6984E+02 | 1.6984E+02 |
| Pop=100 ST=0.9 | 1.6984E+02 | 1.4454E-13 | 1.6984E+02 | 1.6984E+02 | 1.6984E+02 |

**Table 4. The peculiar parameters analysis for F3 problem**

| F3          | Mean       | Std.Dev.   | Median | Min    | Max    |
|-------------|------------|------------|--------|--------|--------|
| Pop=50 ST=0.1 | 3.0389E-12 | 4.6722E-12 | 6.1269E+13 | 3.5396E-16 | 2.0617E-11 |
| Pop=50 ST=0.5 | 7.0400E-12 | 1.4887E-11 | 4.2169E+13 | 1.7825E-14 | 6.6906E-11 |
| Pop=50 ST=0.9 | 9.2863E-12 | 3.2745E-11 | 7.3145E+13 | 1.7528E-15 | 1.7885E-10 |
| Pop=100 ST=0.1 | 5.8605E-12 | 1.5436E-11 | 5.7964E+13 | 1.0574E-14 | 8.0754E-11 |
| Pop=100 ST=0.5 | 3.3289E-12 | 4.5034E-12 | 1.1487E-12 | 1.6826E-15 | 1.6498E-11 |
| Pop=100 ST=0.9 | 3.3492E-12 | 6.1042E-12 | 8.2565E-13 | 8.6298E-16 | 2.6227E-11 |
Table 5. The peculiar parameters analysis for F4 problem

|       | Mean       | Std.Dev.     | Median     | Min         | Max         |
|-------|------------|--------------|------------|-------------|-------------|
| Pop=50 ST=0.1 | 2.7113E+01 | 1.3265E+00  | 2.7390E+01 | 2.3293E+01  | 2.8799E+01  |
| Pop=50 ST=0.5 | 2.7342E+01 | 1.3747E+00  | 2.7418E+01 | 2.3010E+01  | 2.9213E+01  |
| Pop=50 ST=0.9 | 2.7697E+01 | 1.9379E+00  | 2.8347E+01 | 1.9066E+01  | 2.9897E+01  |
| Pop=100 ST=0.1 | 2.8310E+01 | 1.0380E+00  | 2.8700E+01 | 2.5596E+01  | 2.9785E+01  |
| Pop=100 ST=0.5 | 2.8556E+01 | 9.3447E-01  | 2.8662E+01 | 2.5926E+01  | 3.0133E+01  |
| Pop=100 ST=0.9 | 2.8491E+01 | 1.4119E+00  | 2.9136E+01 | 2.3818E+01  | 2.9842E+01  |

It has been seen in results from the tables above for F1 and F2 problems, Pop and ST parameters do not affect the final solution. The same results are obtained with all different conditions. When Pop is taken 50 and ST is taken 0.1 the best results are obtained for F3, F4 and F5 problems. For F6 problem, the best condition is obtained when Pop is taken as 50 and ST is taken as 0.9.

Also, the convergence graphs (Fig.1) of the TSA in six real-life optimization problems prove that the ideal population size is 50 and ST is 0.1.

Table 6. The peculiar parameters analysis for F5 problem

|       | Mean       | Std.Dev.     | Median     | Min         | Max         |
|-------|------------|--------------|------------|-------------|-------------|
| Pop=50 ST=0.1 | 9.1763E-03 | 5.4369E-03  | 7.1746E-03 | 1.1593E-03  | 2.1297E-02  |
| Pop=50 ST=0.5 | 1.0510E-02 | 4.8403E-03  | 9.3799E-03 | 2.9600E-03  | 3.0133E+01  |
| Pop=50 ST=0.9 | 9.8215E-03 | 5.4371E-03  | 1.0676E-02 | 2.9526E-03  | 3.0133E+01  |
| Pop=100 ST=0.1 | 1.0620E-02 | 6.2614E-03  | 9.2922E-03 | 2.2842E-03  | 2.5794E-03  |
| Pop=100 ST=0.5 | 9.7471E-03 | 5.5547E-03  | 9.1413E-03 | 8.5971E-03  | 2.1881E-02  |
| Pop=100 ST=0.9 | 9.7416E-03 | 5.4833E-03  | 8.9009E-03 | 3.1135E-03  | 3.0710E-02  |

Table 7. The peculiar parameters analysis for F6 problem

|       | Mean       | Std.Dev.     | Median     | Min         | Max         |
|-------|------------|--------------|------------|-------------|-------------|
| Pop=50 ST=0.1 | 1.3623E-02 | 7.2883E-03  | 1.3174E-02 | 2.1955E-03  | 3.0215E-02  |
| Pop=50 ST=0.5 | 1.2773E-02 | 6.0711E-03  | 1.1923E-02 | 1.9110E-03  | 2.7479E-02  |
| Pop=50 ST=0.9 | 8.9200E-03 | 4.8231E-03  | 8.6281E-03 | 2.8247E-04  | 2.1422E-02  |
| Pop=100 ST=0.1 | 1.3744E-02 | 6.8534E-03  | 1.3688E-02 | 2.6005E-03  | 2.6798E-02  |
| Pop=100 ST=0.5 | 1.2564E-02 | 6.4110E-03  | 1.1238E-02 | 2.3099E-03  | 2.9027E-02  |
| Pop=100 ST=0.9 | 1.0205E-02 | 4.9953E-03  | 9.8464E-03 | 2.0434E-03  | 2.3014E-02  |

It has been seen in results from the tables above for F1 and F2 problems, Pop and ST parameters do not affect the final solution. The same results are obtained with all different conditions. When Pop is taken 50 and ST is taken 0.1 the best results are obtained for F3, F4 and F5 problems. For F6 problem, the best condition is obtained when Pop is taken as 50 and ST is taken as 0.9.

Also, the convergence graphs (Fig.1) of the TSA in six real-life optimization problems prove that the ideal population size is 50 and ST is 0.1.
Figure 1. Convergence graphs for the benchmark suites’ (F1 to F6)

5. Conclusion
In this study, six continuous unconstrained real-life optimization problems (gas transmission compressor design, optimal capacity of gas production facility, gear train design, frequency modulation sounds parameter identification, the spread spectrum radar polyphase code design with 10 decision variables, the spread spectrum radar polyphase code design with 20 decision variables) were solved with TSA. The experimental results showed that TSA is an alternative solver for these type problems.

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