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Tree Growth Algorithm (TGA): An Effective Metaheuristic Algorithm Inspired by trees' behavior

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Abstract:

In this paper an effective metaheuristic algorithm inspired by trees competition for acquiring light and foods is proposed. Diversification and intensification phases and their tradeoff are detailed in the paper. Also, the proposed approach is verified by using some of benchmark functions commonly used in this research area. To assistance the TGA's efficiency, some of well-known optimization algorithms such as Genetic Algorithm (GA) and Particle Swarm Optimization (PSO) are employed. TGA and these mentioned algorithms are compared in some of used mathematical benchmark in this area. Finally, the obtained results show that the TGA have a good reaction for solving optimization problems.

Keywords:
Trees Growth Algorithm, Combinatorial Optimization, Metaheuristic Algorithm, approximate method.

1. Introduction and Literature review

Generally, the real world problems and decisions are often complex and enormous, hence they cannot be solved by the exact methods in a proper time and cost. There are different methods for solving an optimization problem. These methods are growing very fast in quantity and also in solution approaches. Some of these methods are inspired from natural processes called metaheuristics. Compared to conventional methods based on formal logics or mathematical programming, these meta-heuristic algorithms are generally more powerful [1, 2]. There have been developed more than seventy metaheuristics in last four decades. Most of them are evolutionary based algorithms which conduct the solution population in some iterations into achieve global optimum. Natural organisms, Social behaviors, feeding and mating behaviors especially in birds and fishes, are the main origin of metaheuristics ideas.
These algorithms are used extensively for solving complex optimization problems. Diversification and intensification are the main features of the metaheuristics [3]. The diversification phase guarantees that the algorithm carefully explores the search space whereas the intensification phase searches around the best solutions and selects the best candidates or places. Most of new metaheuristics have been developed based on new solution approaches to be faster is searching feasible areas, especially in large problems.
Generally, Optimization techniques can be divided in two groups, mathematical programming and meta-heuristic algorithms and also, the existing meta-heuristic algorithms maybe divided into two main categories; Evolutionary algorithms and Swarm algorithms.
Evolutionary algorithms inspired by biological evolution and in general the same as the process used to solve optimization problems. Evolutionary strategy (ES) [4], genetic algorithm (GA) [5], and differential evolution (DE) [6] are the most well-known examples of the these algorithms which use biological mechanisms such as crossover and mutation. Harmony search (HS) algorithm is also another evolutionary algorithm proposed by Geem *et al.* [7] which simulates the musicians' behavior when they are searching for better harmonies.
The most well-known example in swarm intelligence is particle swarm optimization (PSO) [8]. The algorithm is based on particle simulation collective behavior (or animals) and also is inspired by the social behavior of bird flocking or fish schooling. Some other well-known swarm algorithms are ant colony optimization (ACO) [9], inspired by the collective foraging behavior of ants, bacterial foraging behavior optimization (BFO) algorithm [10], and bee colony optimization algorithm (BCO), which is based on the simulation of the food foraging behavior of honey bees [11].
Several extensions to the major categories of the swarm intelligence algorithms have been presented in the literature. Yang [3] proposed a novel optimization algorithm, called firefly algorithm (FA), inspired by the firefly's biochemical and social aspects. Yang and Deb [12] formulated a new meta-heuristic algorithm via Levy Flights, called cuckoo search (CS). Hajiaghaei-Keshteli and Aminnayeri formulated a new swarm intelligence algorithm called Keshtel (KA). KA is inspired by feeding the greedy birds namely Keshtel [13, 14]. Besides, there exist some of

recently developed metaheuristics in literature such as, Sine Cosine Algorithm (SCA), Interior Search Algorithm (ISA) and Sperm Whale Algorithm (SWA) [15, 16, 17].
To best our knowledge, about of vegetation only an algorithm under the title Planet Growth Simulation Algorithm (PGSA), published which inspired the growth of plants [18]. So, we find that TGA is a pioneer in the field of trees.
In this paper, a new metaheuristic algorithm, called Trees Growth algorithm (TGA), is introduced for global optimization. Like most of metaheuristics, the TGA has two phases: intensification and diversification of the algorithm. Intensification typically operates by restarting from high quality solutions or by modifying choice rules to favor the inclusion of attributes to these solutions. In this phase, we let the best trees, which satisfy of light absorbing, competition on food source. The novelty approach in this phase ensures that each best tree moves toward a better food source. It means that in the intensification phase, we move just toward the better food source or equivalently, toward the local optimum (or may be the global optimum).
In the diversification phase, we let some of the other trees competition on light absorbing and move to reach new or virginal places (solutions). By well tuning the parameters, the balance between intensification and diversification can be obtained. The performance and efficiency of the TGA was tested on some benchmark and engineering problem. The results confirm the applicability of TGA for solving optimization tasks.
The paper is organized as follows: Section 1 provides a brief review of the meta-heuristic algorithms. Section 2 presents the competition for light, logging of old trees, reproduction of trees and the characteristics of the proposed TGA, including the formulation of the algorithm. Numerical examples are presented in Section 3 to verify the efficiency of the TGA. In Section 4, the performance of the proposed algorithm is also tested using some well-known engineering design problems which have been previously employed to validate different algorithms. Finally, some concluding remarks and suggestions for future research are provided in Section 5.

2. Tree's behavior in forest

For centuries the trees have been considered as passive creations which have no free will. It is believed that their growth has been pre-determined and the only obstruction to their growth would be temporary tension. Since the trees' movement cannot be noticed, it seems that they lack intelligent behavior. Nevertheless, the trees have been scattered on various lands and have occupied 99 percent of the Earth's accumulations. Therefore, there is inconsistency between the vastness of the areas that the plants have occupied and the common belief toward them. Because light has always been easily accessible, since the beginning of time, the sea plants with photosynthesis capability avoided movement and remained stagnant. But, this stagnation led to the increase in competition among life forms since the food was not equally dispersed in various parts of the sea. This led to an evolved generation of the plants which had the ability to move and explore.

2.1. Tree's competition

The trees in the jungle compete over light and nutrients [19], while the trees are still young, they mostly compete over light and as they grow older, they focus more on the nutrients [20]. In this investigation, it has been endeavored to study the greedy behavior of the trees in order to attract light which leads to them raising indirectly toward the Sun. Also the competition among the healthy trees which have received satisfactory amount of light will be discussed.
If we define intelligence as being in harmony with the environment, then the intelligence can be easily observed in the flexible behavior that the plants show in order to get enough light. The growing branches of the trees can sense the nearest competitors and through the usage of ultraviolet light predict the results of their activities, consequently, they have the chance to prevent these results from happening. These processes are mediated through "Phytochrome" molecules [21]. Phytochromes are light sensors and receivers of the plants. Each phytochrome is consisted of a receiving section and a transformation section of light. The receiving section has Tetrapyrrole structure. This section is connected to the transformation section (which is a type of protein) through "cysteine amino acid". This is how the phytochrome is shaped. Phytochromes shift from active to de-active with response to different wavelengths. The de-active phase is changed to active with response to red photons and attract ultraviolet photons better. Through this ability, the phytochromes can estimate the changes in wavelength among other plants [22].
The Sun light has equal amount of red and ultraviolet light. But this proportion reduces in hotbed, since the photosynthesis factors (e.g. chlorophyll) absorbs red light. One of the most important criterion for evaluating the neighboring plants is the degree of change in red and far red light proportion. In high populated areas, the far red light emitting from the leaf, is a clear message which implied that the competitors are near. After the reduced proportion of red to far red light is inferred, the sun favoring plant [23] initiates the growth in length and if this strategy didn't work it would stretch its leaves to the areas in which the changes in the light is less likely to happen. If the growth in length works out, the other responsive aspects of "shade avoidance" would accelerate the flowering process and premature production of the seeds, this phenomenon increases the chance of survival.
Phytochromes were first created in the prokaryote plants ancestors and it seems that they work as light sensors of the simplest from. Although the ability of the phytochromes in transforming the active form to de-active form in prokaryotes with response to sun quality was not of great importance, this ability was evolved and reformed through the evolution of dry plants and turned into a very important and complex sensor which is equal in worth with the visual ability in animals. In other words, the phytochromes can be considered as the eyes of the plants.

The tendency toward light is called phototropism (light tendency) [24]. Charles Darwin, the father of science of evolution, was the first who described this phenomenon scientifically. Through his famous voyage with Biggle (the name of the ship), he kept the birds he had collected on the way. He fed these birds with the buds from a special type of herbal plant named “Yulaf”. Darwin nurtured these buds in small containers in a dark room. One day, this keen naturalist, observed that these plants have leaned toward the only window through which a gleam of light was coming into the room. He conducted experiments based on his observations which he later on published as an article under the title of “The Power of Movement in Plants” [25]. Darwin had proven that the stem of Yulaf bud raised erectly in the absence of light, but the stems of the buds which were exposed to sunlight leaned toward the light. Nevertheless, he mentioned that if the tip of the stems was cut, the bud would not lean toward the light. Further experiments which were conducted based on Darwin’s investigation led to discovering a new hormone in plants called “auxin” [26], [27].

Based on what the founders of auxin has mentioned, this molecule is made on the tip of the stem and causes the asymmetrical growth of the stem on both sides, which means the side which receives less light stores more auxin and grows faster, consequently the stem will lean toward the light. Before all this to happen, the tree must recognize from which side the Sun is shining. The plants, similar to how animals see, can sense the light and the direction from which it is shown, they use specific sensors to analyze different attributes that various types of light have and also evaluate these traits. In order to analyze the light, the tree has to compare two sides (the one that receives the light and the side that doesn’t) in order to recognize the gradient of the light on their body. In order for the trees to analyze the light, they make use of information such as gradient of the light, the duration of the sunlight, the portion of various wavelength in the light, etc. the receiver which give the tree the ability to recognize the one-sided light is called “phototropin”. Phototropins are the molecules which are connected to other phosphate molecule and change their activities. To be exact, Flavin which creates the receiving part of this molecule receives the photon message and transform it to chemical reactions. Such reactions lead to the change in genes and cause the tree to lean toward the light.

Then based on the results of the studies conducted so far, it can be concluded that the trees compete over light and if they are cooped up under bigger trees, they change the direction in which their branches grow and get to the light available in free spaces between other trees as shown in Figure 1.

Figure 1-The competition over light.

2.2. Trees’ reproduction

Similar to many other types of plants, the trees reproduce in three ways, namely, pollination, impregnation, and scattering. Since the trees are stable, through years, many tools for reproduction and survival have improved within them.

2.2.1. Pollination

The trees are either gymnosperm or angiosperm. In gymnosperm trees, the male and female flowers are placed on the same tree. The seeds of these trees are scattered with wind. The male flower has small tubal structure similar to the leaf and flag which creates cloud pollen in early spring. The female flower is the tubal miniature copy of the adult flower which is formed eventually. Angiosperms have created varieties of different flowers some of which are scattered with wind and some others have aromatic calycle or nectar for bugs and other creatures. In some species, the trees are specifically male or female. The flowers of such trees have either compound or separate male and female parts [28].

Pollination with the help of insects: Insects have essential role in plants’ reproduction. Some insects such as bees land on the flowers and the pollens stick to their feet and finally moved to other flowers.

2.2.2. Scattering Seed

The seed of the gymnosperms are usually scattered through wind. The tubes are opened up with response to heat and moisture and release the winged seeds in a specific period of time in order to make sure that some have the chance to survive in appropriate conditions [29]. Some of pine trees have seeds which remain inside the shell until they are moved by other animals.

2.2.3. Self-Reproducing

Some trees have the ability to be shredded, which means while the stem is inside the ground, the root remains in the soil. After destroying the progenitor tree, the reproduction cycle remains. The shallow root creates a new root in adjacency of the progenitor and a new tree will rise.

2.3. Cutting down old and weak trees

Due to some reasons such as road construction, wood smuggling, paddocking, etc. many trees are cut. But we focus our criterion on a utopia in which only the weak trees are cut. Wood-eating beetles and mushroom pests [30], along with micro-pollens, cause the spread of disease in the jungle and, therefore, the foresters have to cut down the sick trees in order to prevent the disease from spreading.

2.4. The proposed Tree Growth Algorithm (TGA)

As mentioned earlier, the proposed algorithm is inspired by the trees competition for acquiring light and foods. In this algorithm, the main phases are divided into four groups.

In one of these groups, called the best trees group, some better trees, due to favorable conditions for growth, will grow further and because of amount of received light be satisfied, their competition focuses for food. Since the growth of trees done slowly, it makes the good trees, basically tall and smooth and most importantly are older than the others, That due to the increasing age of the tree, its

growth rate lower than before (young trees), and their main competition focuses on food in roots.
In the other group, called the competition for light group, some of the trees to reach the light, move to distance between the close best trees under different angles. In the other group, called the remove and replace group, some weak trees, which do not have little growth or for reasons stated in section 2.3 are cut by foresters and replace it with new trees are planted. And finally in the last group, called the reproduction group, the best Trees, because growth has been favorable, they begin to multiply and create new plants. Since that arise near the mother tree inherit some of the factors that location. The detailed algorithm is described below:

1. Randomly generate initial population of trees on the upper and lower bounds and calculate their fitness values.
2. Find the best tree. If there is a minimum optimization problem, the best tree as the minimum objective function and vice versa. This element at jth iteration, T_{GB}^{j} is the global best of it.
3. Allow N1 better solutions have local search using formula (1). (For any solution check several local search. If the new solutions value is better than initial response, replace it.)

$$T_i^{j+1} = \frac{T_i{}^j}{\theta} + rT_i{}^j \qquad (1)$$

That θ is trees reduction rate of power, due to aging, high growth and reduce food around. And r is $U(0,1)$, which due to trees satisfaction of the light, its roots are instructed to move to absorb food for the food processor which growing at a rate of $rT_i{}^j$ units.

4. Move N_2 solutions to distance between the close best solutions under different α angles. To do this, first find the distance between the selected trees and other with formula (2).

$$d_i = \left(\sum_{i=1}^{N1+N2} \left(T^j{}_{N2} - T_i^j\right)^2\right)^{\frac{1}{2}} \quad \& \quad d_i = \begin{cases} d_i & if\ T^j{}_{N2} \neq T_i^j \\ \infty & if\ T^j{}_{N2} = T_i^j \end{cases} \qquad (2)$$

Then choose two solutions x_1 and x_2 with minimal d_i and to get a linear combination between the trees, as shown in Figure 2, the formula (3) used.

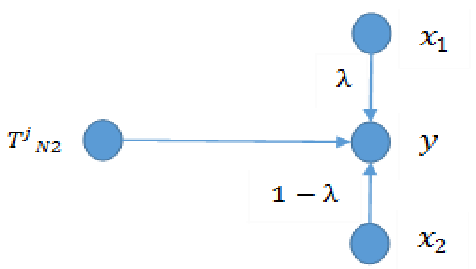


Figure 2 -Linear combination.

$$y = \lambda x_1 + (1-\lambda)x_2 \qquad (3)$$

Finally, to move this tree between two adjacent trees with an $\alpha_i = U(0,1)$ angles, as Figure 3, obtained with formula (4).

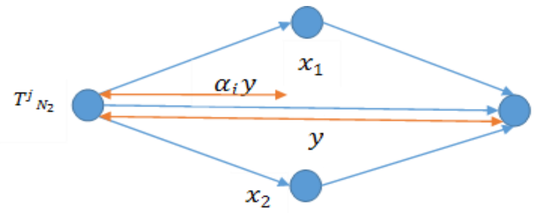


Figure 3 -Moving between two adjacent trees.

$$T^j{}_{N_2} = T^j{}_{N_2} + \alpha_i y \qquad (4)$$

5. Remove N_3 worse solution, and instead of them randomly generated solutions.
6. Create new population (new population $N = N_1 + N_2 + N_3$).
7. N_4 new solution is generated and each new solution operation mask with a best solution (of the population N_1) randomly, then added to the new population (new population= new population + N_4).
8. After sorting the new population, the number of initial population N of this new population we consider as initial population for the next iteration (according to the roulette wheel or tournament or choose the best solutions).

If any of the stop criteria is not satisfied, repeat from step2. The pseudo code of the proposed TGA is presented in Figure 4 and TGA flow chart present in Figure 5.

3. Numerical experiments

In order to evaluate the TGA performance, it is validated using some classical bench-mark problems. The benchmarks contain high dimension problems, and each class has some well-known functions. The descriptions of the functions are presented in Table 1.
Due to the random nature of the TGA and other meta-heuristic algorithms, their performance cannot be judged by the result of a single run. More than one trial with independent population initializations should be made to evaluate the performance of the approach. Therefore, in this study the results are obtained in 10 trials. The population size of 100 were used for each, low- and high-dimensional problems.

Initialization
While any stop criteria is not satisfied
Find the T_{GB}^j

For $i = 1{:}N1$
For $l = 1{:}L$
$T_i^j = \frac{T_i^{j-1}}{\theta} + rT_i^{j-1}$
if $f(T_i^j) \le f(T_i^{j-1})$
$T_i^j = T_i^j$
else $T_i^j = T_i^{j-1}$
end if
end for
end for

For $i = (N1+1){:}(N1+N2)$
$$d_i = \left(\sum_{i=1}^{N1+N2} \left({T^j}_{N2} - T_i^j\right)^2\right)^{\frac{1}{2}}$$
$$d_i = \begin{cases} d_i & if\ {T^j}_{N2} \ne T_i^j \\ \infty & if\ {T^j}_{N2} = T_i^j \end{cases}$$
$x_1 = \mathrm{T}(d_1)$ & $x_2 = Td_2$ *after sorting the* d_i
$y = \lambda x_1 + (1-\lambda)x_2$
${T^j}_{N2} = {T^j}_{N2} + \alpha_i y$
end for

For $i = (N1+N2+1){:}N$
$T_i^j =$ *creat random* T_i^j
end for

For $k = 1{:}N1$
$S_k^j =$ *creat random* S_k^j
$f =$ *rand sample from* $N1$
$S_k^j =$ *do mask operation* S_k^j *with* T_f^j
end for

end while

Figure 4 -Pseudo cod of TGA.

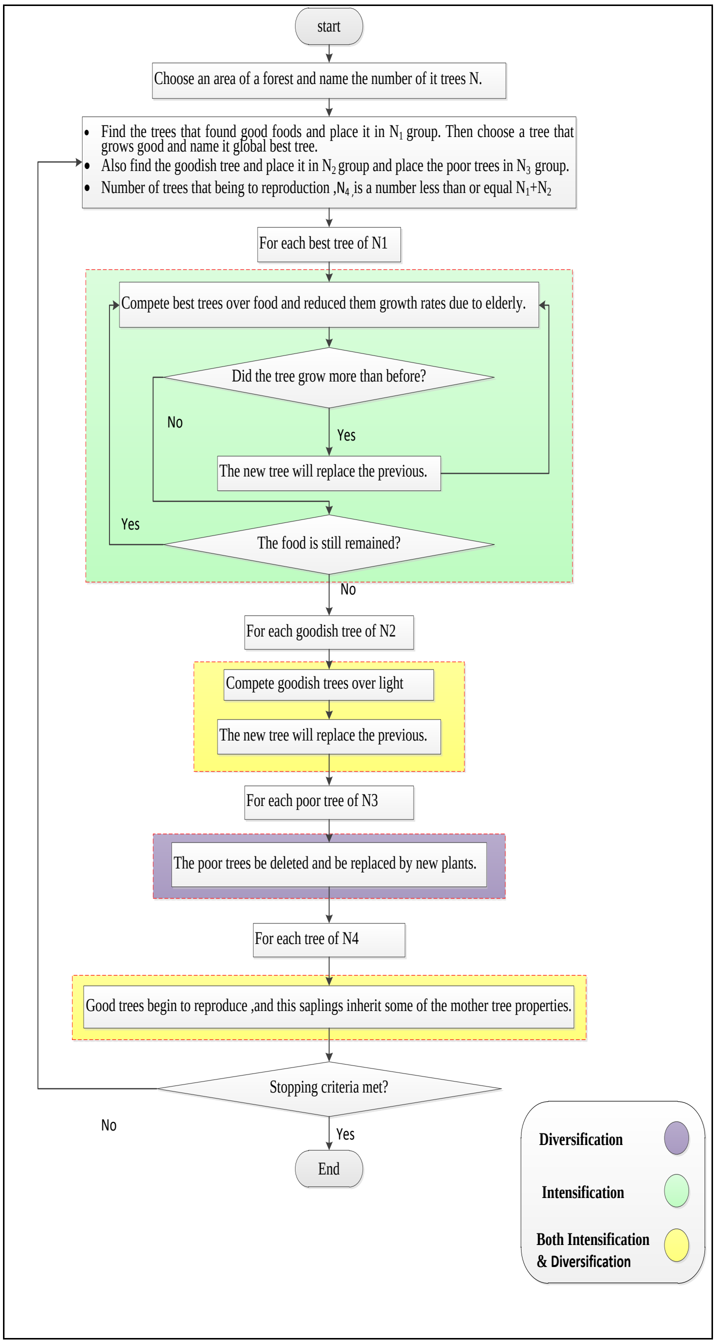


Figure 5 -TGA's Flowchart.

Table 1 -Classical benchmark problems.

ID & Formulation	Name	Dim.	Range	Min
$F1 = 10n + \sum_{i=1}^{n}[x_i^2 - 10\cos(2\pi x_i)]$	Rastrigin	10	(-5.12,5.12)	0
$F2 = \sum_{i=1}^{D}(x_i + 0.5)^2$	Step	30	(-5.12,5.12)	0
$F3 = \sum_{i=1}^{D} ix_i^2$	Sum Squares	30	(-10,10)	0
$F4 = \sum_{i=1}^{n}(100(x_i - x_{i-1}^2)^2 + (x_{i-1} - 1)^2)$	Rosenbrock	10	(-30,30)	0
$F5 = \sum_{i=1}^{n} x_i^2$	Sphere	20	(-100,100)	0

4. Comparative study in standard functions

Moreover, the new TGA is compared with some well-known evolutionary and swarm algorithms. A well-known evolutionary algorithm namely GA is selected for comparison. To implement this algorithm, it is very important to tune its mutation probability (MR) and crossover probability (CR). They are previously tuned some benchmark problems as MR = 0.1 and CR = 0.8. So these values are used in our simulations. Also, another algorithm, PSO as a swarm algorithm is used. The PSO is tuned as acceleration constants equal to (C_1, C_2 =2) and inertia weight (ω) begins with 0.9 and linearly decreases to 0.1 during the iterations to do both exploration and exploitation. In addition, TGA's parameters are shown in Table 2 which these value by using Taguchi method are resulted [31]. Due to the high volume of Taguchi experiments, presentation of them in this article have been refrained.

Table 2 -Parameter values of each algorithm.

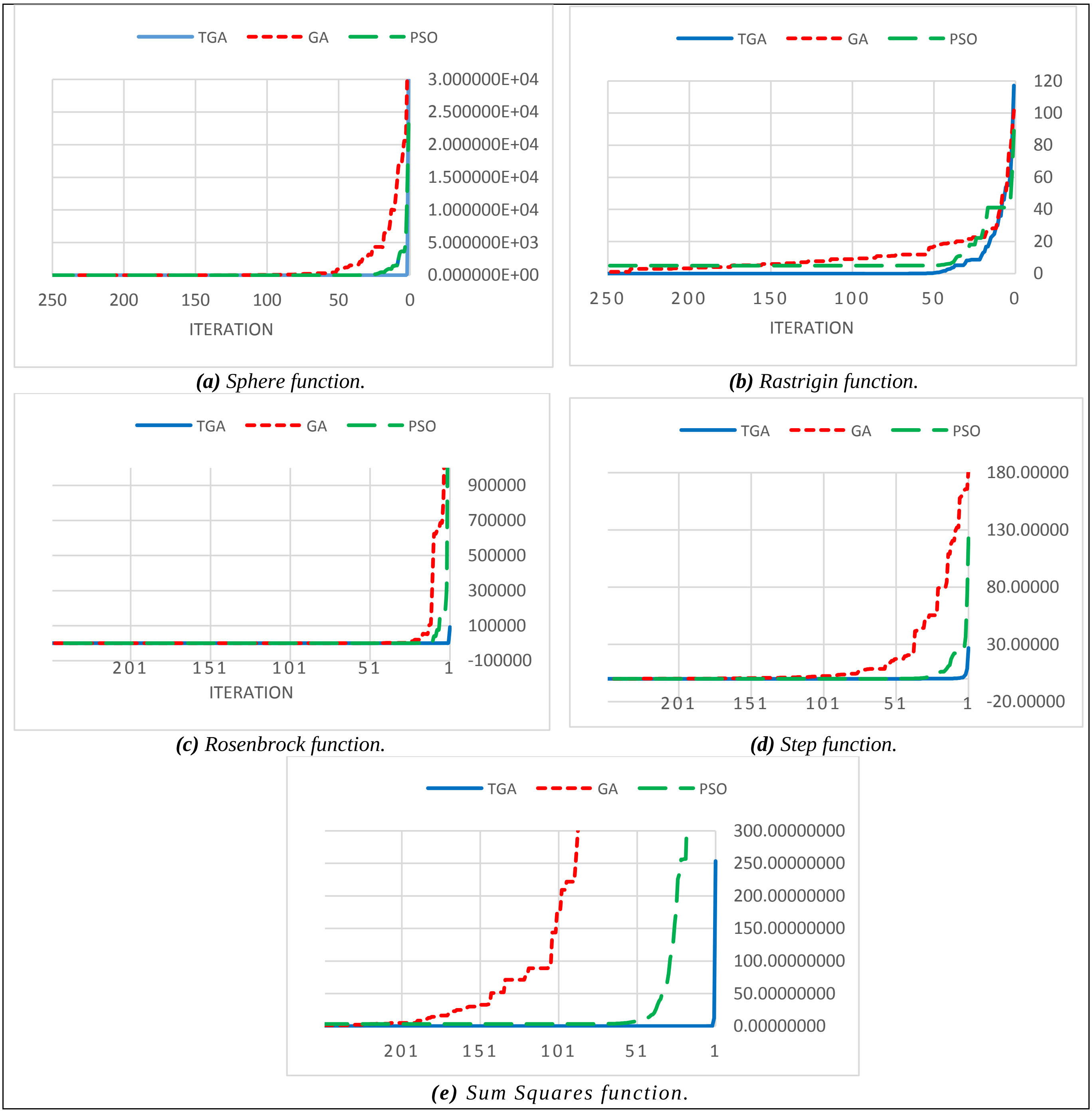
Algorithm	Parameters
GA	Max iteration=250, Initial Population=100, Crossover selection= Roulette wheel CR=0.8, MR=0.1
PSO	Max iteration=250, Initial Population=100, c1=c2=2 , inertia weight=0.9
TGA	Max iteration=250, Initial Population=100, $N_1=40$, $N_2=40$, N_3 = 100- (N_1 + N_2), N_4=30, λ=0.5, θ=1.1

The statistical results of the GA, PSO and TGA on benchmark problems are presented in Table 3. As it is shown, the proposed algorithm is far better than GA and PSO in all cases. The convergence plots of the GA, PSO and TGA on the benchmark problems are also presented in Figure 6.

Table 3 -Normalized statistical results of PSO, GA and TGA for the benchmark problems.

ID	Min	Parameters	PSO	GA	TGA
F1	0	Best	4.974803	1.118972	0
		Mean	5.372838	2.477421	0
		Std. dev.	0.670639	1.232513	0
		Time (s)	7.42	4.38	8.45
F2	0	Best	0.015163	0.028404	0.00145
		Mean	0.040751	0.041669	0.001517
		Std. dev.	0.022841	0.012509	7.64E-05
		Time (s)	7.47	6.84	11.25
F3	0	Best	3.2417	1.2469	0
		Mean	4.966033	2.37693	0
		Std. dev.	1.907171	1.013867	0
		Time (s)	6.59	7.42	10.35
F4	0	Best	2.077951	6.471299	0.565337
		Mean	2.79404	7.527489	0.823109
		Std. dev.	0.965546	0.936433	0.341873
		Time (s)	6.97	5.73	9.32
F5	0	Best	0.008932	0.009245	0
		Mean	0.010251	0.037689	1E-206
		Std. dev.	0.001799	0.024684	0
		Time (s)	8.31	6.84	11.71

At first, the plots clearly confirm that the performance of the proposed algorithms is better than the well-known GA and PSO. The differences between performances are obvious in the convergence plots of high-dimensional problems. The slope of the proposed algorithm is steep and it shows that the TGA converges quickly and rarely stops before finding the global optimum. One of the effective strategies for comparison of meta-heuristic algorithms is the oracle-based view of computation [32]. According to this strategy, the best solution should be found within a certain number of function evaluations. Herein, the best values can be used for comparison because of the equal number of function evaluation value for the methods. Referring to the result presented in Table 3 and based on the oracle-based view, the performances of TGAs are much better than the GA and PSO algorithms. This confirms the robustness of the proposed algorithm.



***(a)** Sphere function.* ***(b)** Rastrigin function.*

***(c)** Rosenbrock function.* ***(d)** Step function.*

***(e)** Sum Squares function.*

Figure 6 -Behavior of employed algorithm in various mathematical benchmark function.

5. Conclusion and future research

In this paper a novel population-based optimization algorithm was proposed as an alternative for solving optimization problems among the current techniques in the literature. Special characteristics of Trees growing behavior had been the basic motivation for development of this new optimization algorithm. This algorithm is different from the previous ones in some new concepts. At first, the TGA is very simple to code and use in different problem types. Also solutions focus in the trees fierce competition for food. It searches cleverly to find the better solution in the neighborhood of possible solutions, in the intensification phase. Besides, by changing or tuning the N_1, N_2, N_3, N_4, θ and λ, the tradeoff between intensification and diversification can be obtained or tuned for a problem by its properties and dimensions.

The introduced algorithm was tested on five benchmark cost functions. The comparison of TGA with standard versions of GA and PSO showed the superiority of TGA in these problems in the algorithms' behavior and finding the global minima.

According to the results of conducted tests, the TGA can be considered as a successful metaheuristic and suitable for optimization problems.

This paper can be expand and improve with several research instructions for future studies. Firstly, binary and multi objective version of this algorithm can be proposed to solve problems with binary and multiple objectives respectively. Secondly, levy flight, mutation, and other evolutionary operators can be integrated to this algorithm for improving its performance. Thirdly, the TGA algorithm can be hybridized with other algorithms in the field of stochastic optimization to improve its performance. Finally, the performance of TGA can be tested on the other real world engineering optimization problems.

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