# Imperialist Competitive Algorithm: An Algorithm for Optimization Inspired by Imperialistic Competition

Esmaeil Atashpaz-Gargari, Caro Lucas

*Abstract*— **This paper proposes an algorithm for optimization inspired by the imperialistic competition. Like other evolutionary ones, the proposed algorithm starts with an initial population. Population individuals called country are in two types: colonies and imperialists that all together form some empires. Imperialistic competition among these empires forms the basis of the proposed evolutionary algorithm. During this competition, weak empires collapse and powerful ones take possession of their colonies. Imperialistic competition hopefully converges to a state in which there exist only one empire and its colonies are in the same position and have the same cost as the imperialist. Applying the proposed algorithm to some of benchmark cost functions, shows its ability in dealing with different types of optimization problems.**

## I. INTRODUCTION

This paper proposes a new evolutionary algorithm for optimization which is inspired by imperialistic competition. From a general point of view, optimization is the process of making something better [1]. Having a function $f(\mathbf{x})$ in optimization, we want to find an argument $\mathbf{x}$ whose relevant cost is optimum (usually minimum).

Different methods have been proposed for solving an optimization problem. Some of these methods are the computer simulation of the natural processes. For example genetic algorithms are a particular class of evolutionary algorithms that evolve a population of candidate solutions to a given problem, using operators inspired by natural genetic variation and natural selection [2]. Simulated annealing is another example. This technique simulates the annealing process in which a substance is heated above its melting temperature and then gradually cooled to produce the crystalline lattice, which minimizes its energy probability distribution [1]. On the other hand, ant colony optimization is inspired by the foraging behavior of real ants [3]. Also the inspiration source of PSO which was formulated by Edward and Kennedy in 1995 was the social behavior of animals, such as bird flocking or fish schooling [1].

The available optimization algorithms are extensively used to solve different optimization problems such as industrial planning, resource allocation, scheduling, decision making, pattern recognition and machine learning. Furthermore, optimization techniques are widely used in many fields such as chemistry, business, industry, engineering and computer science [4-16].

In this paper a new algorithm for global optimization is proposed which is inspired by imperialistic competition. All the countries are divided into two types: imperialist states and colonies. Imperialistic competition is the main part of proposed algorithm and hopefully causes the colonies to converge to the global minimum of the cost function. This paper describes how the imperialistic competition is modeled and implemented among empires. Section II reviews the history of some imperialistic events. In Section III, we introduce the proposed algorithm and study its different parts in details. The proposed algorithm is tested with 4 benchmark functions in Section IV and Section V concludes the paper.

## II. A HISTORICAL REVIEW OF IMPERIALISM

*Imperialism* is the policy of extending the power and rule of a government beyond its own boundaries. A country may attempt to dominate others by direct rule or by less obvious means such as a control of markets for goods or raw materials. The latter is often called *neocolonialism* [17]. In its initial forms, imperialism was just a political control over other countries in order to only use their resources. Also in some cases the reason to control another country was just preventing the opponent imperialist from taking possession of it. No matter what the reason was, the imperialist states were competing strongly for increasing the number of their colonies and spreading their empires over the world. This competition resulted in a development of the powerful empires and the collapse of weaker ones.

Imperialism changed the public attitude toward civilization of the West during $19^{th}$ and $20^{th}$ century. Social Darwinists interpreted imperialism and supported the idea that the culture of West is superior to the East's culture [18]. Imperialism was considered a crusade as a result of this attitude. Then along with all its complications, imperialism made the imperialist states start to develop their colonies (spread their culture) [18]. For example in the middle of 18th century, two opponent imperialists, France and Britain were competing for taking possession of India as a part of their imperialistic ambition to control the entire world [19]. Britain was the winner and could take control of India. After pacifying this country, Britain started to build English speaking schools, roads, railways and telegraph lines. Britain also tried to change the social beliefs and customs that were considered wrong in comparison to western culture. These cultural reforms included the costumes such as self-burning that was followed by Indian widows as a sign of loyalty for

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their husbands. Also they increased the minimum marriage age of daughters. Britain made the same changes in Malaya by abolishing slavery and arbitrary taxes and by making a new system of health care. Indochina is another example. It was a colony of France. France was interested in Indochina for its natural resources and for preventing Britain from increasing its power. Also it was a good place for evangelists to proselytize on people. According to the *assimilation* policy, France intended to construct a new France in Indochina through building French speaking schools and expanding its language and culture. Although these policies could not succeed in increasing the control of imperialists over their colonies, and colonies asked for their political autonomy, they brought about a rapid social and political development for the colonies [19].

In the proposed algorithm, the imperialists do the same for their colonies. Here all the imperialists compete for taking possession of colonies of each other. Also assimilation policy is modeled by moving the colonies toward the imperialists.

### III. THE PROPOSED ALGORITHM

Figure 1 shows the flowchart of the proposed algorithm. Like other evolutionary ones, the proposed algorithm starts with an initial population (countries in the world). Some of the best countries in the population are selected to be the *imperialists* and the rest form the *colonies* of these imperialists. All the colonies of initial population are divided among the mentioned imperialists based on their power. The power of an empire which is the counterpart of the fitness value in GA, is inversely proportional to its cost.

After dividing all colonies among imperialists, these colonies start moving toward their relevant imperialist country. The way by which they move is described in section III.B. The total power of an empire depends on both the power of the imperialist country and the power of its colonies. We will model this fact by defining the total power of an empire by the power of imperialist country plus a percentage of mean power of its colonies.

Then the imperialistic competition begins among all the empires. Any empire that is not able to succeed in this competition and can't increase its power (or at least prevent decreasing its power) will be eliminated from the competition. The imperialistic competition will gradually result in an increase in the power of powerful empires and a decrease in the power of weaker ones. Weak empires will lose their power and ultimately they will collapse. The movement of colonies toward their relevant imperialists along with competition among empires and also the collapse mechanism will hopefully cause all the countries to converge to a state in which there exist just one empire in the world and all the other countries are colonies of that empire. In this ideal new world colonies, have the same position and power as the imperialist.
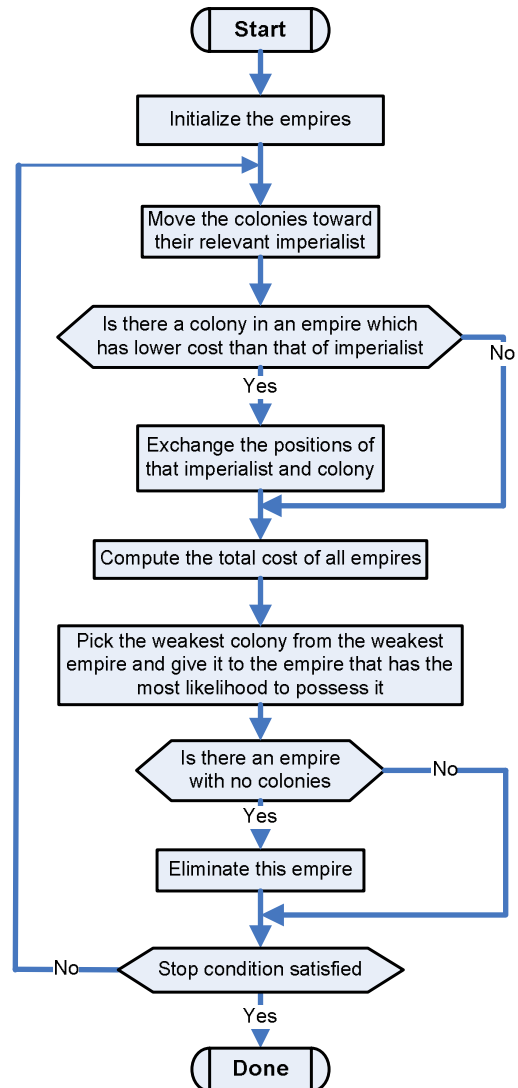


Fig. 1. Flowchart of the proposed algorithm.

#### A. Generating Initial Empires

The goal of optimization is to find an optimal solution in terms of the variables of the problem. We form an array of variable values to be optimized. In GA terminology, this array is called "*chromosome*", but here the term "*country*" is used for this array. In an $N_{var}-$dimensional optimization problem, a country is a $1 \times N_{var}$ array. This array is defined by

$$country = [p_1, p_2, p_3, ..., p_{N_{var}}]$$

The variable values in the country are represented as floating point numbers. The cost of a country is found by evaluating the cost function $f$ at the variables $(p_1, p_2, p_3, ..., p_{N_{var}})$. Then

$$cost = f(country) = f(p_1, p_2, p_3, ..., p_{N_{var}})$$

To start the optimization algorithm we generate the initial population of size $N_{pop}$. We select $N_{imp}$ of the most powerful countries to form the empires. The remaining $N_{col}$ of the population will be the colonies each of which belongs to an empire. Then we have two types of countries; *imperialist* and *colony*.

To form the initial empires, we divide the colonies among imperialists based on their power. That is the initial number of colonies of an empire should be directly proportionate to its power. To divide the colonies among imperialists proportionally, we define the normalized cost of an imperialist by

$$C_n = c_n - \max_i \{c_i\}$$

Where $c_n$ is the cost of $n$th imperialist and $C_n$ is its normalized cost. Having the normalized cost of all imperialists, the normalized power of each imperialist is defined by

$$p_n = \left| \frac{C_n}{\sum_{i=1}^{N_{imp}} C_i} \right|$$

From another point of view, the normalized power of an imperialist is the portion of colonies that should be possessed by that imperialist. Then the initial number of colonies of an empire will be

$$N.C._n = round\{p_n . N_{col}\}$$

Where $N.C._n$ is the initial number of colonies of $n$th empire and $N_{col}$ is the number of all colonies. To divide the colonies, for each imperialist we randomly choose $N.C._n$ of the colonies and give them to it. These colonies along with the imperialist will form $n$th empire. Figure 2 shows the initial population of each empire. As shown in this figure bigger empires have greater number of colonies while weaker ones have less. In this figure imperialist 1 has formed the most powerful empire and has the greatest number of colonies.
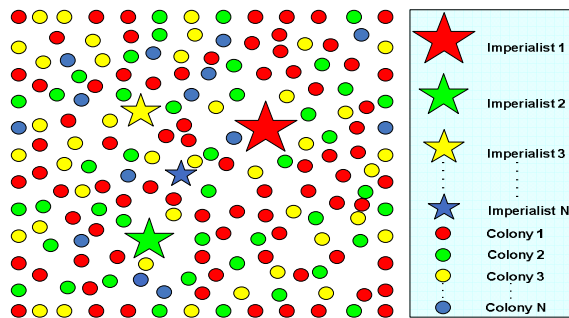


Fig. 2. Generating the initial empires: The more colonies an imperialist possess, the bigger is its relevant ★ mark.

### B. Moving the Colonies of an Empire toward the Imperialist

As mentioned in section II, imperialists countries started to improve their colonies. We have modeled this fact by moving all the colonies toward the imperialist. This movement is shown in figure 3 in which the colony moves toward the imperialist by $x$ units. The new position of colony is shown in a darker color. The direction of the movement is the vector from colony to imperialist. In this figure $x$ is a random variable with uniform (or any proper) distribution. Then for $x$ we have

$$x \sim U(0 , \beta \times d)$$

Where $\beta$ is a number greater than 1 and $d$ is the distance between colony and imperialist. A $\beta > 1$ causes the colonies to get closer to the imperialist state from both sides.
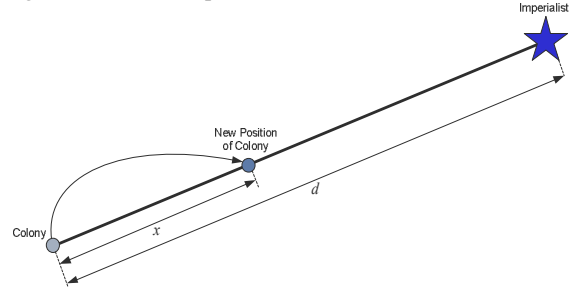


Fig. 3. Moving colonies toward their relevant imperialist

To search different points around the imperialist we add a random amount of deviation to the direction of movement. Figure 4 shows the new direction. In this figure $\theta$ is a random number with uniform (or any proper) distribution. Then

$$\theta \sim U(-\gamma, \gamma)$$

Where γ is a parameter that adjusts the deviation from the original direction. Nevertheless the values of β and γ are arbitrary, in most of our implementation a value of about 2 for β and about π/4 (Rad) for γ have resulted in good convergence of countries to the global minimum.
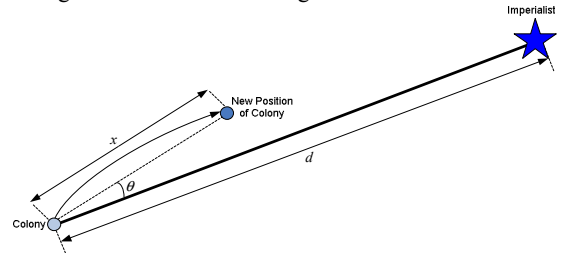


Fig. 4. Moving colonies toward their relevant imperialist in a randomly deviated direction.

### C. Exchanging Positions of the Imperialist and a Colony

While moving toward the imperialist, a colony may reach to a position with lower cost than that of imperialist. In such a case, the imperialist moves to the position of that colony and vise versa. Then algorithm will continue by the imperialist in a new position and then colonies start moving toward this position. Figure 5a depicts the position exchange between a colony and the imperialist. In this figure the best colony of the empire is shown in a darker color. This colony has a lower cost than that of imperialist. Figure 5b shows the whole empire after exchanging the position of the imperialist and that colony.
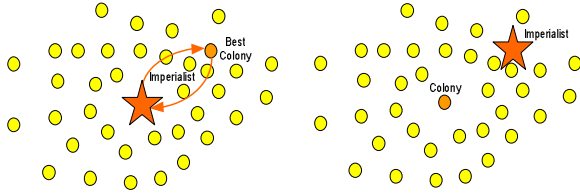
Fig. 5a. Exchanging the positions of a colony and the imperialist

Fig. 5b. The entire empire after position exchange

### D. Total Power of an Empire

Total power of an empire is mainly affected by the power of imperialist country. But the power of the colonies of an empire has an effect, albeit negligible, on the total power of that empire. We have modeled this fact by defining the total cost by

$$T.C._n = Cost(imperialist_n) + \xi \, mean\{Cost(colonies \ of \ empire_n)\}$$

Where $T.C._n$ is the total cost of the $n$th empire and $\xi$ is a positive number which is considered to be less than 1. A little value for $\xi$ causes the total power of the empire to be determined by just the imperialist and increasing it will increase the role of the colonies in determining the total power of an empire. We have used the value of 0.1 for $\xi$ in most of our implementation.

### E. Imperialistic Competition

As mentioned in section II, all empires try to take possession of colonies of other empires and control them. This imperialistic competition gradually brings about a decrease in the power of weaker empires and an increase in the power of more powerful ones. We model this competition by just picking some (usually one) of the weakest colonies of the weakest empires and making a competition among all empires to possess these (this) colonies. Figure 6 shows a big picture of the modeled imperialistic competition. Based on their total power, in this competition, each of empires will have a likelihood of taking possession of the mentioned colonies. In other words these colonies will not be possessed by the most powerful empires, but these empires will be more likely to possess them.
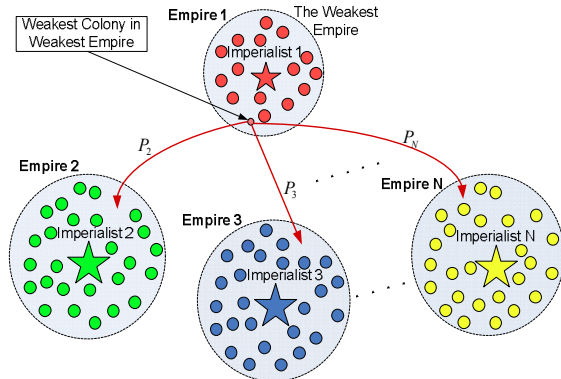


Fig. 6. Imperialistic competition. The more powerful an empire is, the more likely it will possess the weakest colony of the weakest empire.

To start the competition, first, we find the possession probability of each empire based on its total power.

The normalized total cost is simply obtained by

$$N.T.C._n = T.C._n - \max_i\{T.C._i\}$$

Where $T.C._n$ and $N.T.C._n$ are respectively total cost and normalized total cost of $n$th empire. Having the normalized total cost, the possession probability of each empire is given by

$$p_{p_n} = \left| \frac{N.T.C._n}{\sum_{i=1}^{N_{imp}} N.T.C._i} \right|$$

To divide the mentioned colonies among empires based on the possession probability of them, we form the vector $\mathbf{P}$ as

$$\mathbf{P} = \left[ p_{p_1}, p_{p_2}, p_{p_3}, ..., p_{p_{N_{imp}}} \right]$$

Then we create a vector with the same size as $\mathbf{P}$ whose elements are uniformly distributed random numbers.

$$\mathbf{R} = \left[ r_1, r_2, r_3, ..., r_{N_{imp}} \right]$$

$$r_1, r_2, r_3, ..., r_{N_{imp}} \sim U(0,1)$$

Then we form vector $\mathbf{D}$ by simply subtracting $\mathbf{R}$ from $\mathbf{P}$.

$$\mathbf{D} = \mathbf{P} - \mathbf{R} = \left[ D_1, D_2, D_3, ..., D_{N_{imp}} \right]$$

$$= \left[ p_{p_1} - r_1, \ p_{p_2} - r_2, \ p_{p_3} - r_3, ..., p_{p_{N_{imp}}} - r_{N_{imp}} \right]$$

Referring to vector $\mathbf{D}$ we will hand the mentioned colonies to an empire whose relevant index in $\mathbf{D}$ is maximum.

### F. Eliminating the Powerless Empires

Powerless empires will collapse in the imperialistic competition and their colonies will be divided among other empires. In modeling collapse mechanism different criteria can be defined for considering an empire powerless. In most of our implementation, we assume an empire collapsed and eliminate it when it loses all of its colonies.

### G. Convergence

After a while all the empires except the most powerful one will collapse and all the colonies will be under the control of this unique empire. In this ideal new world all the colonies will have the same positions and same costs and they will be controlled by an imperialist with the same position and cost as themselves. In this ideal world, there is no difference not only among colonies but also between colonies and imperialist. In such a condition we put an end to the imperialistic competition and stop the algorithm.

In the next part we apply the proposed algorithm to some of benchmark problems in the realm of optimization. The main steps in the algorithm are summarized in the pseudo-code shown in figure 7.

Fig. 7. Pseudo code for the proposed algorithm.

## IV. EXPERIMENTAL STUDIES

In this section, the proposed algorithm is tested with 4 benchmark functions [1]. All these problems are minimization problems. The details of these functions are listed in Appendix. We will study problem $G_1$ in details but will just list the results of other ones. Figure 8 shows a 3D plot of function in problem $G_1$. The global minimum of this function in interval $0 < x, y > 10$ is located in $(x, y) = (9.039, 8.668)$ and has the cost of -18.5547.
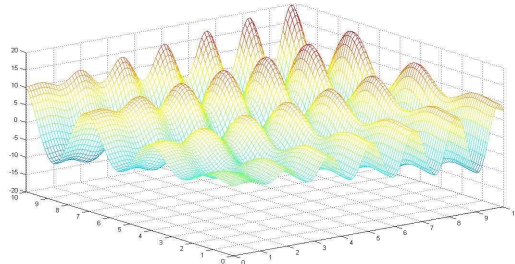


Fig. 8. 3D plot of function in problem $G_1$

The initial population of 100 countries is shown in Figure 9. We choose 8 of the best countries of initial population to form the imperialists and take possession of other 140 ones. The imperialists are shown by ★ marks in different colors and the colonies of each imperialist are shown by • in the same color as the imperialist. The more colonies an imperialist possess, the bigger is its relevant ★ mark. Figures 10, 11, and 12 show the countries at iterations 4, 10 and 15 (convergence). It can be seen that at iteration 4, the imperialists are located at local minima of the function and one of them has reached to the global minimum point. At iteration 10, only 2 imperialists are remained and the others have collapsed. At iteration 15 all the imperialists are collapsed and just one is controlling all the colonies. It is easily observable that colonies are in the same position as the imperialist (those that are in different positions are due to mutation at final iteration).
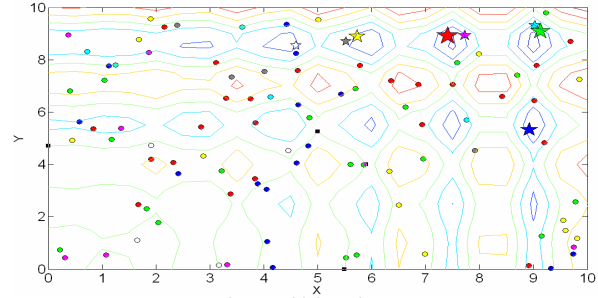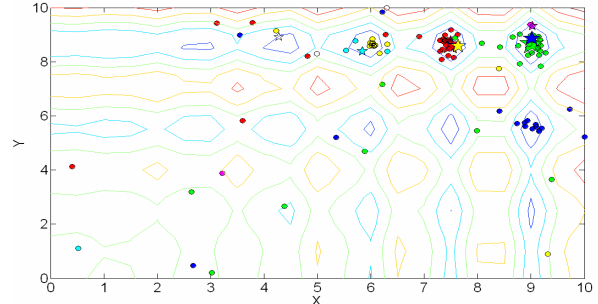


Fig. 9. Initial empires.



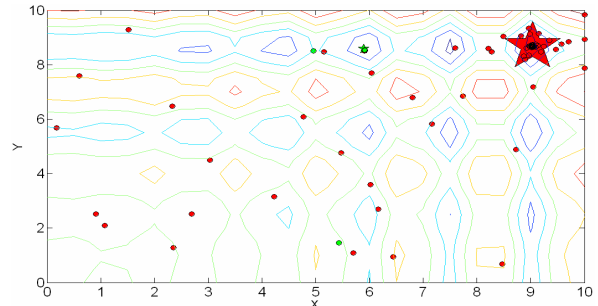Fig. 10. Empires at iteration 4: all the empires are gathered in the local minima.



Fig. 11. Empires at iteration 10: All the empires except two of them are collapsed.
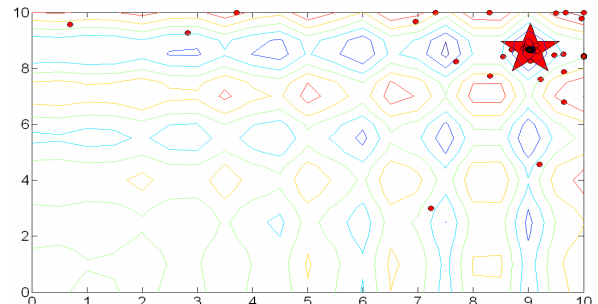


Fig. 12. Empires at iteration 15: All the countries have converged to the global minimum of the function being controlled by a unique empire.

Figure 13 depicts the mean and minimum cost of all imperialists versus iteration. As shown in this figure, the global minimum of the function is found at iteration 7. But up until iteration 15, other imperialists are also in good positions and are able to compete. But collapsing one by one, at iteration 15 only one of them is alive; one that reached the global minimum sooner.
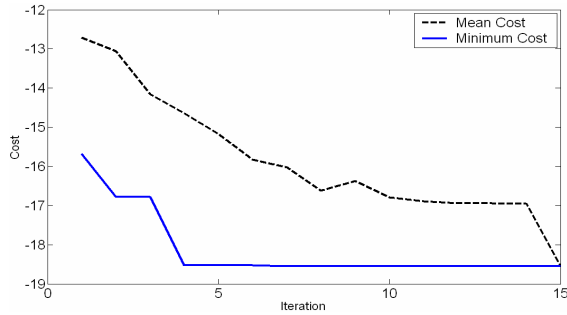
Fig. 13. Mean and minimum cost of all imperialists versus iteration in problem $G_1$.

We also applied a continuous GA and PSO to this problem. To make a comparison among these methods we choose the initial population of 100 for all of them. In continuous GA, mutation and selection rates are 0.3 and 0.5 respectively and for PSO, cognitive and social parameters are equal to 1 and 3 respectively. The mean and minimum cost of all population versus generation in GA is shown in figure 14. Figure 15 shows the average and best cost of population versus generation in PSO. The results show that the proposed method and GA have reached the global minimum in almost the same iterations (about iteration 7). But up until iteration about 25 PSO has not reached the global minimum. Also in the proposed algorithm, it takes only 15 iterations for mean and minimum cost of all imperialists to be equal. However in PSO the equivalent iterations are about 200.
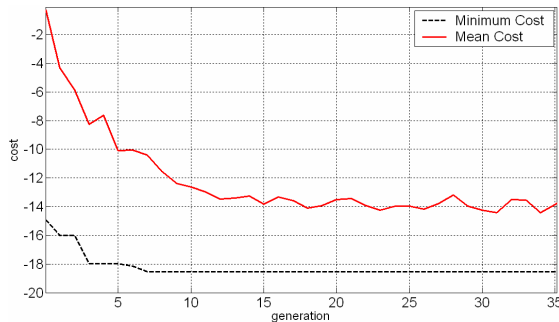


Fig. 14. Mean and minimum cost of population in problem $G_1$ versus generation for a continuous GA
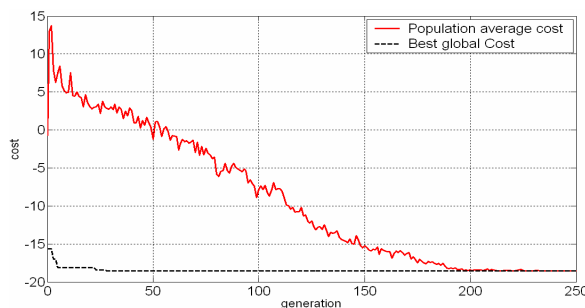


Fig. 15. Average and best cost of population in problem $G_1$ versus generation for Particle Swarm Optimization.

We also used the proposed algorithm to find the global minimum of functions in problems $G_2, G_3$ and $G_4$. The numbers of initial countries and initial empires used in problem $G_2$ are 150 and 15, in problem $G_3$ are 50 and 5 and in problem $G_4$ are 80 and 8, respectively. Figure 16 shows the mean and minimum cost of all imperialists in problems $G_2$, $G_3$ and $G_4$.
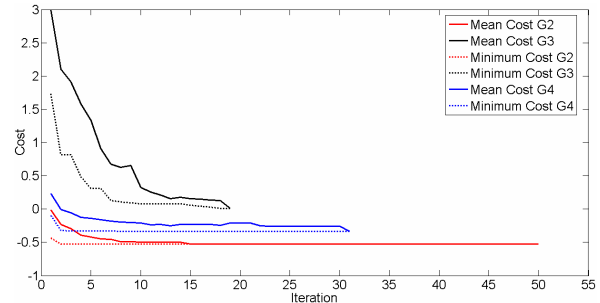


Fig. 16. Mean and minimum cost of all imperialists versus iteration in problems $G_2, G_3$, and $G_4$.

## V. CONCLUSIONS AND FUTURE WORK

In this paper, an optimization algorithm based on modeling the imperialistic competition is proposed. Each individual of the population is called country. The population is divided into two groups: colonies and imperialist states. The competition among imperialists to take possession of the colonies of each other forms the core of this algorithm and hopefully results in the convergence of countries to the global minimum of the problem. In this competition the weak empires collapse gradually and finally there is only one imperialist that all the other countries are its colonies. The algorithm is tested by 4 benchmark functions and the results shows that the algorithm finds the global minimum these functions successfully. Also the algorithm is compared with PSO and GA for one of the benchmark functions. The proposed algorithm is applied to only some of standard optimization problems. Therefore our future work will consist in using the proposed algorithm to solve some of more practical optimization problems. Also in specific applications, some parts of the algorithm can be modified in order to improve the algorithm execution speed.

## APPENDIX

Problem $G_1$ :

$$f = x.\sin(4x) + 1.1y.\sin(2y)$$
$$0 < x, y > 10 \ , \ minimum : f(0.9039, 0.8668) = -18.5547$$

Problem $G_2$ :

$$f = 0.5 + \frac{\sin^2 \sqrt{x^2 + y^2} - 0.5}{1 + 0.1(x^2 + y^2)}$$

$$-\infty < x, y > +\infty \ , \ minimum : f(1.897, 1.006) = -0.5231$$

Problem $G_3$ :

$$f = (x^2 + y^2)^{0.25} \times \sin\left\{30\left[(x+0.5)^2 + y^2\right]^{0.1}\right\} + |x| + |y|$$

$-\infty < x, y > +\infty$ , $minimum : f(0,0) = 0$

Problem $G_4$ :

$$f = J_0(x^2 + y^2) + 0.1|1-x| + 0.1|1-y|$$

$-\infty < x, y > +\infty$ , $minimum : f(1, 1.6606) = -0.3356$

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