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Sinusoidal Chaotic Genetic Algorithm for Constrained Optimization: Recent Trends in Applied Optimization

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Abstract:

Genetic algorithms deliver powerful and effective algorithms for analysing and solving the optimization issues. The Main goal of this research is to propose Sinusoidal chaotic Map Based genetic algorithm in order to solve general nonlinear programming issues whose name is "*Sinusoidal chaotic genetic algorithm (SCGA)*". The integration of genetic algorithm and Sinusoidal chaotic topical seeking algorithm shall provide the best of the two optimization methods while balancing their drawbacks. chaos theory has innate features that can promote the genetic techniques via enriching it to get away from stuck at topical trap and decrease the time taken to reach the final global solution of the optimization system. The proposed algorithm was implemented on some benchmark problems in addition to bi-objective real-life supply production planning application, which transformed to nonlinear programming using new parabolic membership function. The simulation results declare that applying chaotic agent is considered to be an effective method to enhance the execution of the genetic techniques.

Keywords: Constrained Programming, Parabolic Membership Function, Genetic Algorithms, Chaotic Map.

1. INTRODUCTION.

Optimization science is an art of a prescribed selecting of the superior choice amongst a given set of choices. Thus, optimization is considered as a very vital research topic for scientists, and there still many open problems in its area [1-3]

Nonlinear programming optimization cases NLP have several important real life applications, for example, engineering design, engineering of structures, cell layout designing, and many other different applications in the real world [3,4]. Traditionally, the NLP cases are classified to two major groups: unconstrained NLP cases and constrained NLP cases [5]. On the first hand, for the unconstrained cases, there are several methods that are categorized to two main classes of methods and named as "*direct search*" and "*gradient search*" based approaches. On the other hand, the constrained methods class are categorized to an un-lineal and lineal techniques. All of those optimization approaches are given a name: "*classical optimization methods*", that are insufficiently robust in non-convex, discrete, noisy and non-differentiable search universes [6 -9].

Recently, Certain optimization techniques have been appeared and have been named advanced techniques which are different from the old ones. These techniques simulate some features and some behaviour of swarm of birds, molecular neurobiology, biological and etc. Moreover, these algorithms can overcome many of difficulties of classical optimization methods and has minimal chance to become 'stuck' in a topical optimal gin. Also, they did not need that the objective and constraints functions to be continuous, derivable or even convex [10]. There are several well-known advanced algorithms, from which (SA) [11, 12], (GA) [13,14], (PSO) [15,16], (ACO) [17,18], neural-network-based methods [19,20] etc.

One of the advanced algorithms is the Genetic algorithm GA which considered to be an effective and robust universal optimization search technique because Genetic algorithm has an ability to go away from topical optima traps and tends to find the universal optima regions. With all of this, their strengthening operation in the best region is often imprecise. Consequently, in order to develop the ability of genetic algorithm for global search by enriching it with topical search procedure, several hybrid new methods have been proposed [21 -22]. Many researchers seek to improve the solution quality by proposing hybrid optimization algorithms, which present an integration between chaos theory [23,24] and evolutionary algorithms [25-28]. Also, the mathematical concepts of theory of chaos has been introduced and implemented to different aspects of the optimization theory.

The main goal of our research is to propose a new mixed technique for selecting the best choice from many others for solving restrictive NLP problem. The proposed algorithm is Sinusoidal chaotic Map Based modified genetic algorithm optimization for Constrained NLP. The proposed approach is a novel optimization system that enriches genetic algorithm with Sinusoidal chaotic Map. The potential characteristics of Sinusoidal chaotic Map based local search can improve optimization algorithms capability to escape from local solutions (i.e., not stuck at local optimal trap) and accelerate the convergence of the suggested algorithm to reach to the universal optimum selection. The simulation results have been proved the notability of the suggested hybrid technique to locate the accurate optimal solution.

2. CONSTRAINED NONLINEAR PROGRAMMING CASES (CNLC).

In the definition of the common nonlinear programming problem, the objective chosen functions $f(\bar{x})$ and control chosen functions $g_i(\bar{x})$ are nonlinear function. Finding the optimum solution of a nonlinear function is especially difficult; consequently, no one know an approach for locating the universal best solution to the common nonlinear programming case.

As stated in [3], let $\bar{x}$ be continuous variables, the general NLPC with respect to continuous variables is to select $\bar{x}$ such that

$$Min \;\; f(\bar{x}),$$
$$where \qquad \bar{x} = (x_1, x_2, \dots, x_n) \in R^n \tag{1}$$

While $\bar{x} = (x_1, x_2, \dots, x_n) \in G$ (feasible space). The search space is the set $H \subseteq R^n$, and the feasible part of the search space is symbolized by the set $G \subseteq H$. Normally, the seeking universe is described by n-dimensional rectangular hypercube in R^n. Where the domains of used variables can be defined as lower and upper bounds:

$$Lift(i) \le x_i \le Right(i), \quad 1 \le i \le n$$

While, the suitable set F is realized as that part of the seeking universe S which satisfies an extra set of control restrictions:

$$g_i(\bar{x}) \le 0 \text{ and } i = 1,..,m \tag{2}$$

The following is the definition of NLPC:

$$NLPP : \operatorname{Max} f(\bar{x})$$
$$s.t.$$
$$G = \{\bar{x} \in R^n \mid \psi_i(\bar{x}) \le 0,\ i = 1,2...,k \ and \ \phi_j(\bar{x}) = 0,\ j = k+1,2,..,m\}$$
$$H = \{\bar{x} \in R^n \mid L_i \le \bar{x}_i \le U_i,\ i = 1,2,..,n\} \tag{3}$$

All set of predefined nonlinear equations $\phi_j(\bar{x}) = 0,\ j = k+1,2,..,m$ are transformed to a set of pairs of related inequalities: $-\varepsilon \le \phi_j(\bar{x}) \le \varepsilon$ with additional parameter (ε) which define the degree of precision of the system. So, only nonlinear inequalities are used by our proposed approach.

$$NLPP : Max \;\; f(\bar{x})$$
$$s.t.$$
$$G = \{\bar{x} \in R^n \mid g_i(\bar{x}) \le 0,\ i = 1, 2..., 2m - k\}$$
$$H = \{\bar{x} \in R^n \mid L_i \le \bar{x}_i \le U_i,\ i = 1, 2, ..., n\} \tag{4}$$

3. BASIC CONCEPTS AND HISTORY OF GENETIC ALGORITHMS (GAs)

In 1975, based on Darwin's concept of Evolution, GA was initiated by Holland [29]. GA begins with a group of candidate solutions (called individuals) or randomly generated chromosome. The candidate solutions are evolved during several iterations seeking to converge to the fittest solution. New offspring are generated by applying GA operators (mutation and crossover). Crossover includes splitting of two or more chromosomes and combining them in order to produce new offspring. On the prime hand, mutation includes changing a single gene of a chromosome. Then, the individual chromosomes are evaluated using a certain criteria and the elite selections are saved to the following generation. This process is continued till the stopping rule is satisfied. The better fitness individual chromosome is taken as the end selection of the problem. Figure 1 shows a typical GA's flow chart.

GA has several advantages. The most important GA's advantages are as it doing well for universal seeking in optimization cases, particularly, when the goal function is non-convex, discrete or have many topical minima. These advantages lead to some potential disadvantages. GA disadvantages because an extra information like gradients are not used by GA and its rate of convergence is slow with well-behaved goal functions.

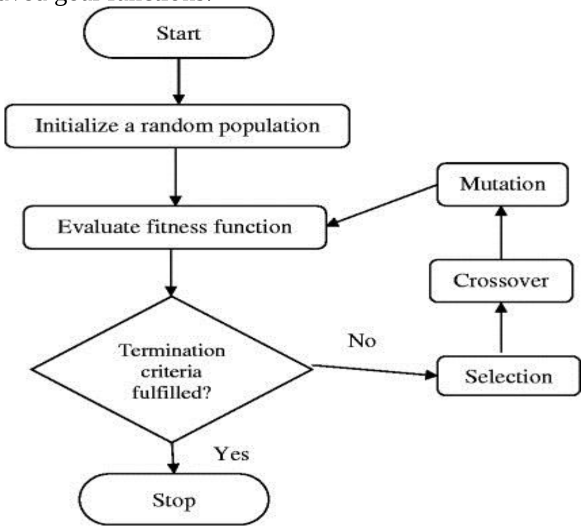

Fig. 1. Genetic Algorithm's flow chart

4. CHAOS THEORY

Chaos was presented by Henon (1976) [**23**] and it was summarized by Lorenz[24]. Chaos theory refers to the study of chaotic dynamical systems as water flows, weather patterns, and anatomical functions. Chaotic systems represented by nonlinear dynamical systems that are strongly sensible to the starting state, while tiny variations in starting state cause large variations in the end output of system. Chaos theory could be coupled with the theory of optimization to speed up the optimum search procedure in order to get the universal best selection.

Chaotic functions is defined as a certain map that introduces some type of chaotic behaviour. Those chaotic functions can be represented by a discrete-time type or a continuous-time type. In this research we concentrate on Discrete chaotic functions which usually represented in the form of iterated functions. For the interest reader certain well-defined chaotic functions introduced in the scientific search area can be found in [30].

5. THE NOVEL SUGGESTED ALGORITHM

Here, we have introduced the suggested novel algorithm for solving constrained NLP, Sinusoidal chaotic search based genetic algorithm (SCGA), which is hybridization between GAs and chaotic map based local search algorithm. The proposed algorithm consists of two stages (called phases). For the prime stage, GA is applied as universal optimization algorithm to get out an inexact optimal selection for the CNLP case. After that, in the second stage (phase), Sinusoidal chaotic search is executed to speed up the convergence rate and enhance the selection quality of the problem. The detailed description concept of the proposed system can be explained as shown in the next steps:

Stage I: GA

Step1. Initial Population

Firstly all search variables are initially randomly created satisfying the entire range of search variables (i.e., satisfying the search space).

Step2. Reference Common Point

Only one feasible reference common point is required by the proposed method (i.e., feasible point satisfying the set of constraints) to complete the evolution Mating, the interested reader may find additional information on [31-32].

Step 3. Modified Repairing

The main concept of this scheme is firstly, distinguish all possible solutions (individuals that are feasible) in each algorithm population from those that are infeasible. Secondly, repair each infeasible individual to become feasible. Using this method, the algorithm co-evolves all set of infeasible solutions till they turn to be feasible. The description of repair algorithm is as follow:

Suppose that we have a point satisfying the search universe $\boldsymbol{b} \in \boldsymbol{H}, \boldsymbol{b} \notin \boldsymbol{G}$ (while $\boldsymbol{H}$ is the seeking universe and $\boldsymbol{G}$ is the feasible space). The algorithm detect one reference point, say $\boldsymbol{a} \in \boldsymbol{G}$ and randomly generates points $\bar{\boldsymbol{A}}$ from the segment line between the two points $\boldsymbol{b}, \boldsymbol{a}$, where this segment line might be expanded on the two sides equally [31, 32], which determined by parameter $\mu \in [0,1]$. Then , new feasible individuals α_1, α_2 are written as follows:

$$\alpha_1 = \gamma.\boldsymbol{b} + (1-\gamma).\boldsymbol{a}, \quad \alpha_2 = (1-\gamma).\boldsymbol{b} + \gamma.\boldsymbol{a}$$

While $\gamma = (2\mu + 1)\delta - \mu$, $\mu \in [0,1]$ is a user specified parameters, and $\delta \in [0,1]$ is a number that is generated randomly.

Step 4. Evaluation

In the fitness evaluation stage, for each individual, we determine a ranking function (ranking metric) of chromosomes fitness. This ranking metric determines which individual will be stil exist to the coming descent via detecting chromosomes that have higher fitness. **Step 5. Generating new population**

To generate a new proper population, we implement the genetic operators (crossover and mutation), the detailed description are as follows:

Ranking: Using fitness value for each individual, the population of individuals was ranked, which return a vector of scalar containing the individual fitness value, this vector is used to calculate their probabilities that are needed for the choice operation.

Selection: Roulette wheel election is an efficient genetic algorithm operator applied in GA for choosing useful candidates for recombination. The simulation may be considered by supposing a roulette wheel in which each potential selection corresponds to a cavity on the wheel, the volume of the cavity is proportional to the probability of choosing of the selected solution[14].

Crossover: crossover combines two or more parents to create a novel offspring with crossover prescribed probability P_c. In this research, we implement Multi-point crossover [33].

Mutation: Mutation is implemented to maintain genotype diversity during the algorithm evolution. Mutation is considered as a genetic algorithm agent, that change values of one or more gene in a chromosome from its starting values [34]. In this research, we implement real valued mutation; where we added a generated randomly values to each variable with a prescribed probability $P_m <<< 1$.

Step 6. Stopping rule

The optimization method is ended after predetermined number of generations

MaxGen (*MaxGen* is a user defined parameter) has been achieved.

Stage II : Sinusoidal map based local search

Chaotic mapping-based topical seeking improve the algorithm capability to disturb x^* in a specified local neighborhood of search space[35]. The procedure of chaotic Sinusoidal map based local search was described and implemented as following:

Step 1. Chaotic search boundary's variance range

The span of chaotic mapping-based-local search (i.e., upper bound and lower bound for each variable) $\{[L_i, U_i],\ i = 1, 2, \ldots, N\}$ is determined by the relation $L_i > x_i^* - \xi,\ U_i < x_i^* + \xi$; where ξ is radius of chaos search scheme, see Figure 2 .

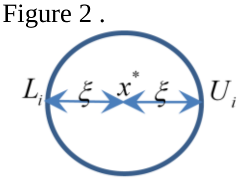

Fig 2: The range of chaotic mapping-based-local search

Step 2. Sinusoidal Chaotic Variables Generator

Perform chaos map by applying the Sinusoidal Chaotic map operator. Sinusoidal Chaotic map [30] is performed according to the following discrete dynamical system which defined by the iterative function, where Chaos variable z^k is created as described in the coming iterative formula:

$$z_{t+1} = \sin(\pi z_t); \tag{5}$$

Step 3. Mapping chaotic variable

Generated chaotic element z^k is transformed into the variance period $[L_i, U_i]$ of the selected optimization variable by the following relation:

$$x_i^k = L_i + (U_i - L_i) z^k \tag{6}$$

Step 4. Updating the better selected value

If $f\left(x^k\right) < f\left(x^*\right)$ then put $x^* = x^k$, else stop the iteration process.

Step 5. Chaotic Search Stopping Criteria

If the function value $f\left(x^*\right)$ has not get better for all predetermined k iteration, then end the iteration operation and set it out as the better reached solution value.

The flow chart of the proposed hybrid algorithm is illustrated in figure 3, while figure 4 declares the structure of the pseudo code of the proposed chaotic local search,

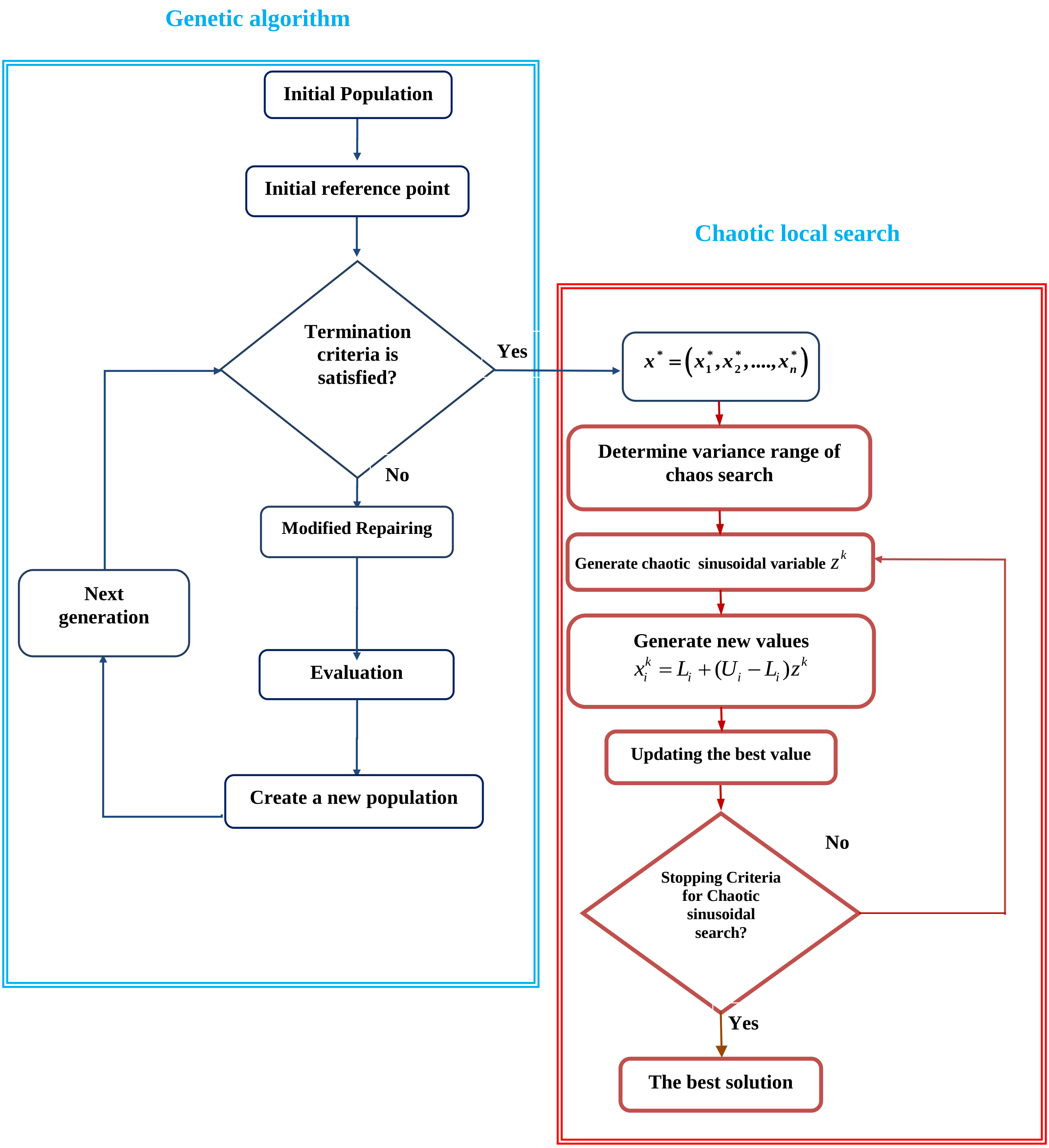

Fig. 3. SCGA procedure for nonlinear optimization problems

Given $x^* = \left(x_1^*, x_2^*, ..., x_n^*\right)$, ε , and number of chaotic iteration k

While: $f\left(x^*\right)$ **is improved**

Begin

$k \leftarrow 1$

Generate z^k **using Sinusoidal map**

$x_i^k = L_i + (U_i - L_i) z^k$

If $f(x^k) < f(x^*)$

then $x^* = x^k$

Else if $f(x^k) \geq f(x^*)$

continue,

End if

If termination criteria satisfied,

Break

End if

$k \leftarrow k+1$

End while

Fig. 4. Pseudo code of the algorithm of Sinusoidal map based local search

6. SIMULATION ANALYSIS

In this section, we investigate the validation of the proposed algorithm, where we present eight nonlinear constraint problems [36-40], which was solved using different evolutionary algorithms [14,37,41,42] by Intel Core i5 processors and implemented in MATLAB 12. Also the proposed algorithm was implemented to solve bi-objective real life supply production planning application of minimizing harmful pollution substance and maximizing revenue. The parameters and the operators that are implemented in the simulation run are declared in Table 1.

Table 1. The algorithm parameters/operators

Parameters/Operators	Value/Type
Population size	100
Number of GA iteration	100
Chaos search iteration	30
Chaotic map	Sinusoidal
Crossover type	Single point
Probability of Crossover	0.88
Mutation type	Polynomial mutation
probability of Mutation	0.03
Selection type	Roulette Wheel

M1[14,39]

$$
\begin{aligned}
& Min \quad f(y) = 0.8356891 y_1 y_5 + 5.3578547 y_3^2 \\
& S.t. \\
& C_1(y) = 80.51249 + 0.0071317 y_2 y_5 + 0.0029955 y_1 y_2 + 0.0021813 y_3^2 \\
& C_2(y) = 85.334407 + 0.0056858 y_2 y_5 + 0.00026 y_1 y_4 + 0.0022053 y_3 y_5 \\
& C_3(y) = 9.300961 + 0.0047026 y_3 y_5 + 0.0012547 y_1 y_3 + 0.0019085 y_3 y_4 \\
& 90 \leq C_1(y) \leq 110, 0 \leq C_2(y) \leq 92, \ \ 20 \leq C_3(y) \leq 25 \\
& 78 \leq y_1 \leq 102, \ 33 \leq y_2 \leq 45, \ 27 \leq y_3 \leq 45, \ 27 \leq y_4 \leq 45, \ 27 \leq y_5 \leq 45
\end{aligned}
$$

M2[14,40]

$$
\begin{aligned}
Min\ \ f(x) = {} & y_1^2 + y_2^2 + y_1 y_2 - 14y_1 - 16y_2 + (y_3 - 10)^2 \\
& + 4(y_4 - 5)^2 + (y_5 - 3)^2 + 2(y_6 - 1)^2 + 5y_7^2 \\
& + 7(y_8 - 11)^2 + 2(y_9 - 11)^2 + (y_{10} - 7)^2 + 45,
\end{aligned}
$$

Subject to

$$
\begin{aligned}
& C_1(x) = 105 - 4y_1 - 5y_2 + 3y_7 - 9y_8 \geq 0, \\
& C_2(x) = -10y_1 + 8y_2 + 17y_7 - 2y_8 \geq 0, \\
& C_3(x) = 8y_1 - 2y_2 + 5y_9 + 2y_{10} + 12 \geq 0, \\
& C_4(x) = -3(y_1 - 2)^2 - 4(y_2 - 3)^2 - 2y_3^2 + 7y_4 + 120 \geq 0, \\
& C_5(x) = -5y_1^2 - 8y_2 - (y_3 - 6)^2 + 2y_4 + 40 \geq 0, \\
& C_6(x) = -y_1^2 - 2(y_2 - 2)^2 + 2y_1 y_2 - 14y_5 + 6y_6 \geq 0, \\
& C_7(x) = -0.5(y_1 - 8)^2 - 2(y_2 - 4)^2 - 3y_5^2 + y_6 + 30 \geq 0, \\
& C_8(x) = 3y_1 - 6y_2 - 12(y_9 - 8)^2 + 7y_{10} \geq 0, \\
& -10 \leq y_i \leq 10, i = 1, \ldots 10.
\end{aligned}
$$

M3[38]

$$
Min\ \ f(x) = 5\sum_{i=1}^{4} y_i - 5\sum_{i=1}^{4} y_i^2 - \sum_{i=5}^{13} y_i
$$

Subject to

$$
\begin{aligned}
& C_1(y) = 2y_1 + 2y_2 + y_{10} + y_{11} - 10 \leq 0, \\
& C_2(y) = 2y_1 + 2y_2 + y_{10} + y_{12} - 10 \leq 0 \\
& C_3(y) = 2y_2 + 2y_3 + y_{11} + y_{12} - 10 \leq 0, \\
& C_4(y) = -8y_1 + y_{10} \leq 0 \\
& C_5(y) = -8y_2 + y_{11} \leq 0, C_6(y) = -8y_3 + y_{12} \leq 0,\ C_7(y) = -2y_4 - y_5 + y_{10} \leq 0, \\
& C_8(y) = -2y_6 - y_7 + y_{10} \leq 0,\ C_9(y) = -2y_8 - y_9 + y_{12} \leq 0, \\
& 0 \leq y_i \leq 1, i = 1, \ldots 9, 0 \leq y_i \leq 100, i = 10, 11, 12, 0 \leq y_{13} \leq 1.
\end{aligned}
$$

M4[38]

$$
\text{Min } f(y) = \left| \frac{\sum_{i=1}^{n} \cos^4 y_i - \prod_{i=1}^{n} \cos^2 y_i}{\sqrt{\sum_{i=1}^{n} i y_i^2}} \right|
$$

$$
\textit{Subject to}\ \ C_1(y) = 0.75 - \prod_{i=1}^{n} y_i \leq 0;\ C_2(y) = \sum_{i=1}^{n} y_i - 7.5n \leq 0;\ 0 \leq y_i \leq 10, i = 1, \ldots, 20.
$$

M5 [36,14]

$$
\begin{aligned}
&Min \quad f_w(y) = 1.10471 y_1^2 y_2 + .04811 y_3 y_4 (14.0 + y_2) \\
&Subject\ to \\
&g_1(y) = 13600 - r(y) \geq 0, g_2(y) = 30000 - \sigma(y) \geq 0, \\
&g_3(y) = x_4 - x_1 \geq 0, g_4(y) = p_c(y) - 6000 \geq 0, \\
&g_5(y) = 0.25 - \delta(y) \geq 0, 0.125 \leq y_1 \leq 10, 0.1 \leq y_2, y_3, y_4 \leq 10. \\
&\text{where,} \\
&r(y) = \sqrt{(r'(y))^2 + (r''(y))^2 + l(r'(y) r''(y)) / \sqrt{0.25 * (y_2^2 + (y_1 + y_3)^2)}} \\
&\sigma(y) = \frac{504000}{y_3^2 y_4}, p_c(y) = 64746.022(1 - 0.0282346t) y_3 y_4^3, \\
&\delta(y) = \frac{2.1952}{y_3^3 y_4}, r'(y) = \frac{6000}{\sqrt{2} y_1 y_2}, \\
&r''(y) = \frac{6000(14.0 + 0.5x_2)\sqrt{0.25 * (y_2^2 + (y_1 + y_3)^2)}}{2\{0.707 y_1 y_2 (y_2^2 / 12 + 0.25(y_1 + y_3)^2)\}}.
\end{aligned}
$$

M6 [36,14]

$$
\begin{aligned}
&Min \quad f(y) = (y_1 - 10)^3 + (y_2 - 20)^3 \\
&Subject\ to \\
&g_1(x) = (y_1 - 5)^2 + (y_2 - 5)^2 - 100 \geq 0 \\
&g_2(x) = -(y_2 - 5)^2 - (y_1 - 6)^2 + 82.81 \geq 0 \\
&13 \leq y_i \leq 100, \quad 0 \leq y_2 \leq 100.
\end{aligned}
$$

M7 [36,14]

$$
\begin{aligned}
&Min \quad f(x) = (y_1 - 1)(y_1 - 2)(y_1 - 3) + y_3 \\
&Subject\ to \quad C_1(x) = y_3 \wedge 2 - y_2 \wedge 2 - x_1 \wedge 2 \geq 0, \ C_2(y) = y_1 \wedge 2 + y_2 \wedge 2 + y_3 \wedge 2 - 4 \geq 0 \\
&0 \leq y_1, \ 0 \leq y_2, \quad 0 \leq y_3 \leq 5
\end{aligned}
$$

M8 [36,14]

$$
\begin{aligned}
&Min \quad f(y) = 5y_1 + 50000 / y_1 + 20y_2 + 75000 / y_2 + 10y_3 + 144000 / y_3 \\
&Subject\ to \quad C_1(y) = 1 - 4 / y_1 - 32 / y_2 - 120 / y_3 \geq 0, \quad 10^{-5} \leq y_i, i = 1,2,3
\end{aligned}
$$

Table 2 summarize the results for different four evolutionary algorithms, where we list the best solution, worst solution, mean, and standard deviations after 20 independent runs for each problem, the obtained results by applying the proposed algorithm are better than the corresponding ones obtained from other algorithms.

Table 2: statistical analysis of the proposed algorithm versus other evolutionary algorithms

Function	Optimal	Status	Evolutionary Algorithms				
			Proposed algorithm	[37]	[12]	[14]	[18]
M1	**-30665.55**	**Best solution**	**-30665.55**	-30665.55	-30665.51	-30665.35	-30665.53
		Mean	**-30666.51**	-30666.31	-30666.26	-30666.31	-30666.53
		Worst solution	**-30665.16**	-30665.53	-30665.33	-30665.23	-30665.53
		St. Dev.	**6.1E-06**	5.1E-02	4.3E-04	4.2E-01	5.1E-09
M2	**24.8641**	**Best solution**	**24. 64**	24.8641	24.9631	24.9641	24.3062
		Mean	**24.641**	24.6621	24.7691	24.8621	24.4312
		Worst solution	**24. 8641**	24.6521	24.6601	24.6532	24.6721
		St. Dev.	**2E-04**	3.3E-02	4.3E-02	4.2E-03	5.1E-01
M3	**-15**	**Best solution**	**-15**	-15	-15	-15	-15
		Mean	**-15**	-15	-15	-15	-14.492
		Worst solution	**-15**	-15	-15	-15	-14.354
		St. Dev.	**0**	0	0	0	9E-01
M4	**-0.80325**	**Best solution**	**-0.80325**	-0.80325	-0.81325	-0.83215	-0.80315
		Mean	**-0.80325**	-0.81325	-0.81212	-0.84325	-0.81325
		Worst solution	**-0.80325**	-0.82325	-0.81532	-0.86312	-0.82335
		St. Dev.	**0**	5.3E-02	4.6E-04	4.7E-02	5.7E-03
M5	**2.381021**	**Best solution**	**2.381021**	2.381021	2.38302	2.381054	2.38104
		Mean	**2.382041**	2.392041	2.38405	2.381092	2.38710
		Worst solution	**2.383061**	2.393061	2.38602	2.381063	2.3900
		St. Dev.	**4.1E-05**	9.3E-06	5.3E-04	3.2E-03	3.2E-05
M6	**-6961.81**	**Best solution**	**-6961.81**	-6961.71	-6961.35	-6961.51	-6961.34
		Mean	**-6961.61**	-6961.53	-6961.21	-6961.42	-6961.21
		Worst solution	**-6961.21**	-6961.45	-6961.01	-6961.34	-6961.12
		St. Dev.	**5E-04**	3E-04	1.2E-03	2.2E-05	1.7E-04
M7	**-4.5857**	**Best solution**	**-4.5857**	-4.5807	-4.5432	-4.5800	-4.5850
		Mean	**-4.5502**	-4.5750	-4.5401	-4.5741	-4.5843
		Worst solution	**-4.5403**	-4.5634	-4.5390	-4.5707	-4.5821
		St. Dev.	**2E-06**	3.3E-04	3.1E-03	1.4E-02	2.2E-04
M8	**6299.84**	**Best solution**	**6299.6**	6299.84	6299.73	6300.10	6299.01
		Mean	**6299.74**	6299.70	6299.72	6300.04	6299.03
		Worst solution	**6299.84**	6299.04	6299.43	6301.21	6299
		St. Dev.	**2.1E-04**	4.1E-04	5.2E-03	5.1E-04	2.2E-03

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Figures 5-12 illustrate the convergence analysis of the proposed algorithm for these eight problems

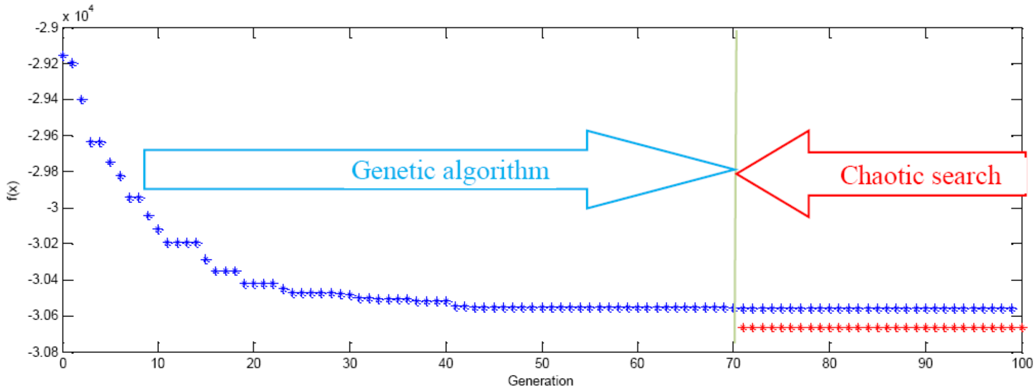

Fig. 5. Convergence analysis for problem M1

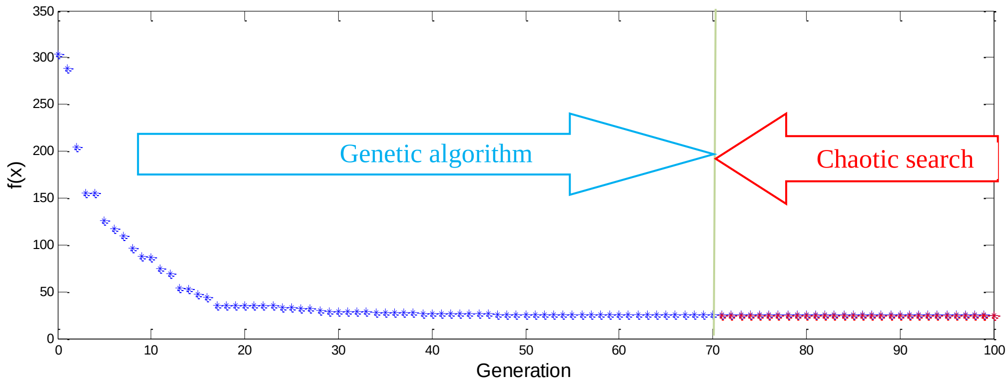

Fig. 6. Convergence analysis for problem M2

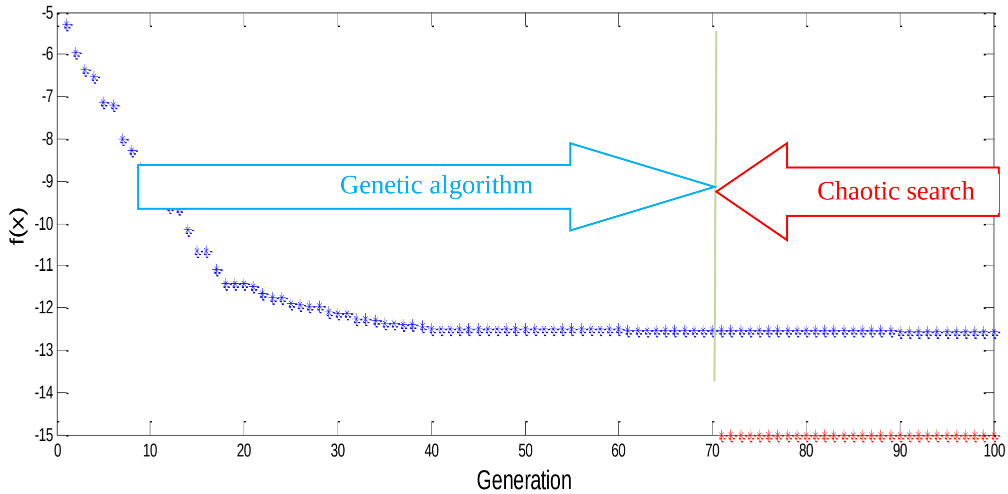

Fig.7. Convergence analysis for problem M3

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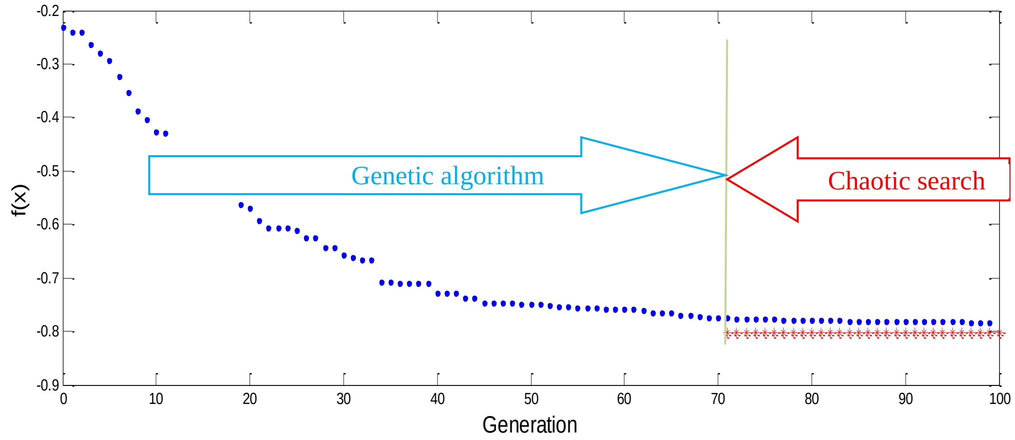

Fig.8. Convergence analysis for problem M4

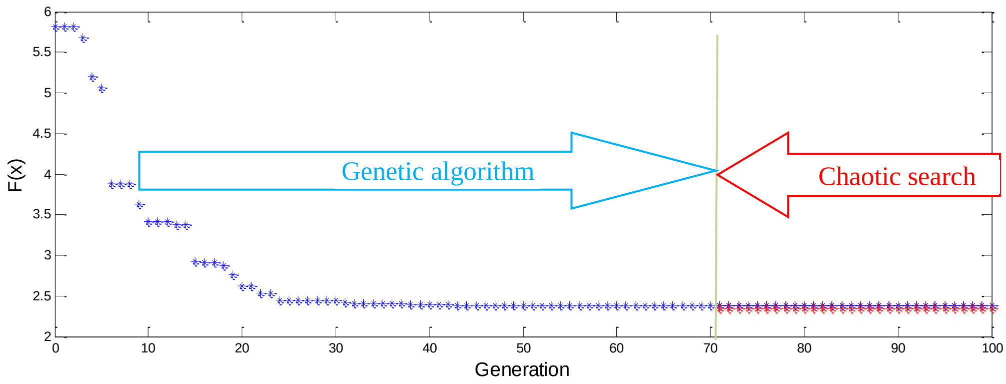

Fig. 9. Convergence analysis for problem M5

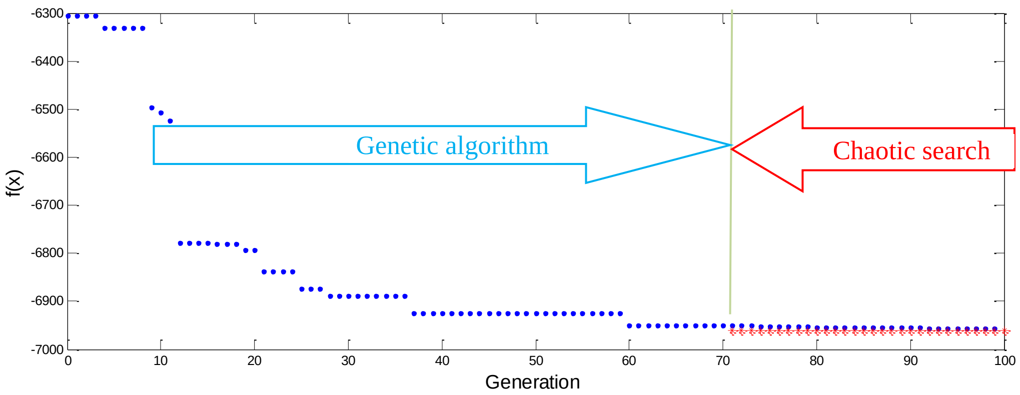

Fig. 10. Convergence analysis for problem M6

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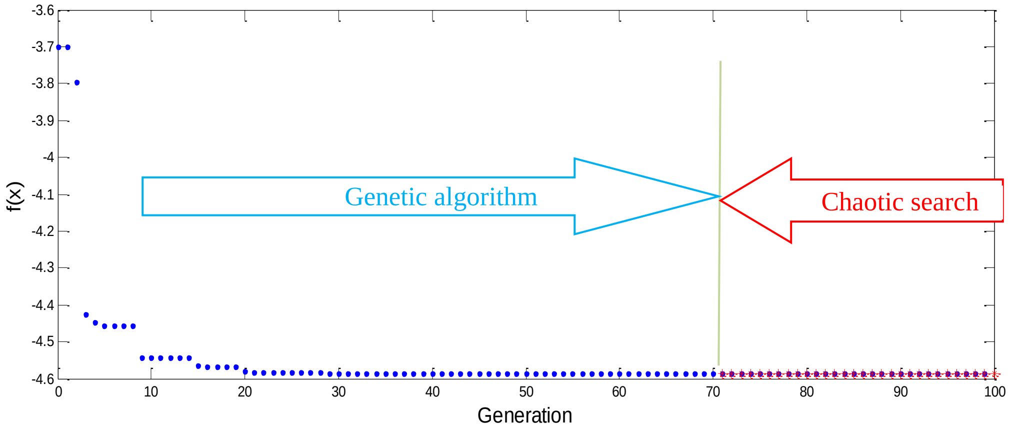

Fig. 11. Convergence analysis for problem M7

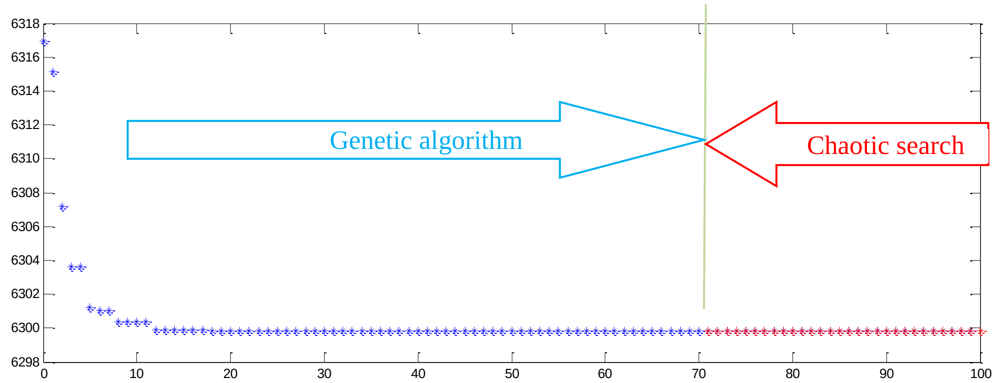

Fig. 12. Convergence analysis for problem M8

Table 3 gives the percentage saving of time computation due to using chaotic local search; the obtained results declare that using chaotic local search saving around 30% as an average for all eight problems. It was emphasized that significant savings can be achieved via the chaotic local search, which evolves the total performance of the proposed algorithm.

Table 3: Percentage saving for test problems

Problem	M1	M2	M3	M4	M5	M6	M7	M8
Percentage saving	70%	30%	47.5%	36%	36%	22%	0%	0%

Fuzzy Bi-Objective Linear Programming [34,44]:

A certain factory creates 3 different outputs A, B and C. To create 1 unit of A it requires 2 ton of raw matter I, 3 ton of raw matter II, and 4 ton of raw matter III To create 1 unit of output B it requires 8 ton of raw matter I, and 1 ton of raw matter II. To create 1 unit of output C it requires 4 ton of raw matter I, 4 ton of raw matter II, and 2 ton of raw matter III. At present prices, the company anticipates to market output A at a price of 5×10^6 \$/unit, output B at a price of 10×10^6 \$/unit, and output C at a price 12×10^6 \$/unit. However, over production operation, creating 1 unit of output A gives 1 ton of hurtful pollution material, creating 1 unit of output B gives 2 ton of hurtful pollution material, and creating 1 unit of output C gives 2 ton of hurtful pollution material. he goals are to maximize total income and to minimize total given hurtful pollution material. The availability of raw materials are 100 ton, 50 ton, and 50 ton for Raw materials I,II, and III respectively.

This real world problem can be mathematically formulated as bi-objective linear programming as following:

$$\begin{aligned}
&Max\ \ F_0 = 5y_1 + 10y_2 + 12y_3 (revenue)\\
&Min\ \ F_1 = y_1 + 2y_2 + 2y_3 (pollution)\\
&s.t.\\
&2y_1 + 8y_2 + 4y_3 \le 100,\ 3y_1 + y_2 + 4y_3 \le 50,\ 4y_1 + 2y_3 \le 50\\
&y_1, y_2, y_3 \ge 0
\end{aligned}$$

This can be written as follows:

$$Max\ \ F_0 = cy\ ,\ Min\ \ F_1 = dy\ ,\quad s.t.\ \ Ay \le b,\ \ y \ge 0$$

Where,

$$x = [y_1 \quad y_2 \quad y_3]^T,\ c^T = \begin{bmatrix} 5 \\ 10 \\ 12 \end{bmatrix},\ d^T = \begin{bmatrix} 1 \\ 2 \\ 2 \end{bmatrix}$$

$$A = \begin{bmatrix} 2 & 8 & 4 \\ 3 & 1 & 4 \\ 4 & 0 & 2 \end{bmatrix},\ b = [100 \quad 50 \quad 50]^T$$

By solving each objective separately using Linear Programming Calculator [45], we get:

$$Case\ 1: Max\ \ F_0 = cy\ \ \ s.t.\ Ay \le b,\ \ y \ge 0.$$

$$y = (0, 7.14, 10.71),\ F_0 = 200,\ F_1 = 35.71$$

$$Case\ \ 2: Min\ F_1 = dy\ \ \ s.t.\ Ay \le b,\ \ y \ge 0.$$

$$y = (0, 0, 0),\ F_0 = 0,\ F_1 = 0$$

In problem (1), Maximum income is 200 million \$, but this solution gives 35.71 ton of hurtful pollution material.

In problem (2), Minimum hurtful pollution material is 0 ton, which would mean 0 \$ of total income. As we can observe, these two goals (Maximum income and Minimum hurtful pollution material) are in conflict with each other (i.e., when maximize total income, hurtful pollution material increases, also when Minimize hurtful pollution material, total income decreases).

To get an adjustment solution with respect to opacity and satisfaction degree, two aims were defined as follows. [43] :

Aim 1 : Must obtain at least 75% of maximum total income (150×10^6 \$), but we would prefer to get 100% of maximum total income (200×10^6 \$).

Aim 2 : The total pollution matter must not exceed 30 ton , but we would prefer to get ton of pollution matter.

These two aims can be mathematically modelled into fuzzy nonlinear programming using modified parabolic membership function as follows:

Let μ is the degree of membership function.

For goal 1, the value in the interval [150,200] would be described by a nonlinear function (Parabolic function) $(F_0 - 150)^2 / 2500$, thus we get the following membership function which declared in figure 13

$$\mu(F_0) = 0,\ \text{when}\ \ 0 \le F_0 \le 150\ \ \text{and}\ \mu(F_0) = \frac{(F_0 - 50)^2}{2500}\ \text{when}\ 150 \le F_0 \le 200$$

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As declared in figure 13.

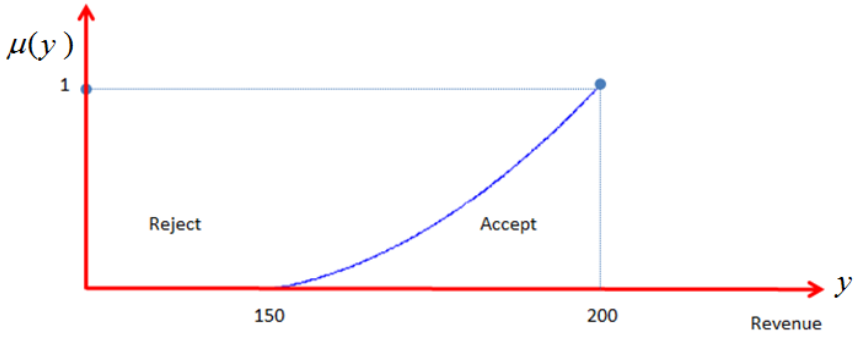

Fig. 13. Parabolic Membership Function for Revenue

For goal 2, the value in the interval [0,30] would be described by a nonlinear function (Parabolic function) $1-\sqrt{\frac{F_1}{30}}$, thus we get the following membership function as declared in figure 14

$$\mu(F_1)=0,\ \text{when}\ 30\le F_1\ \text{and}\ \mu(F_1)=1-\sqrt{\frac{F_1}{30}}\ \text{when}\ 0\le \mathrm{F}_1\le 30$$

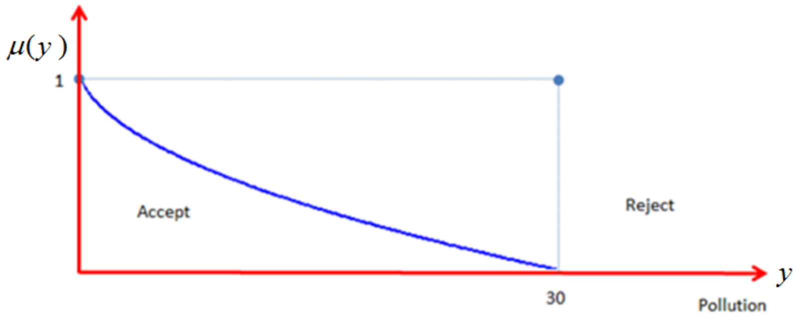

Fig. 14. Parabolic Membership Function for pollution

By implementing the concept of fuzzy membership function, the objectives of our multi-objective problem will be defined as follows

$$Max\,\{\min\{F_0,F_1\}\}s.t.\ \mathrm{Ay}\le \mathrm{b},\mathrm{y}\ge 0.$$

This would means that we want to find the value of which is dependent upon which would maximize membership to both sets, since $F_0=cy\,,F_1=dy$ we get the following nonlinear programming problem:

$$Max\ \lambda$$

$$s.t.$$

$$\lambda\le\frac{(5y_1+10y_2+12y_3-150)^2}{2500},$$

$$\lambda\le 1-\sqrt{\frac{y_1+2y_2+2y_3}{30}}$$

$$2y_1+8y_2+4y_3\le 100$$

$$3y_1+y_2+4y_3\le 50$$

$$4y_1+2y_3\le 50$$

$$y_1,y_2,y_3\ge 0$$

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Solving this nonlinear programming problem using our proposed approach, we obtain:

$$\lambda = 0.0461, y_1 = 0, y_2 = 1.5331, y_3 = 12.1167$$

Figure 15 represent a convergence curve for the proposed approach

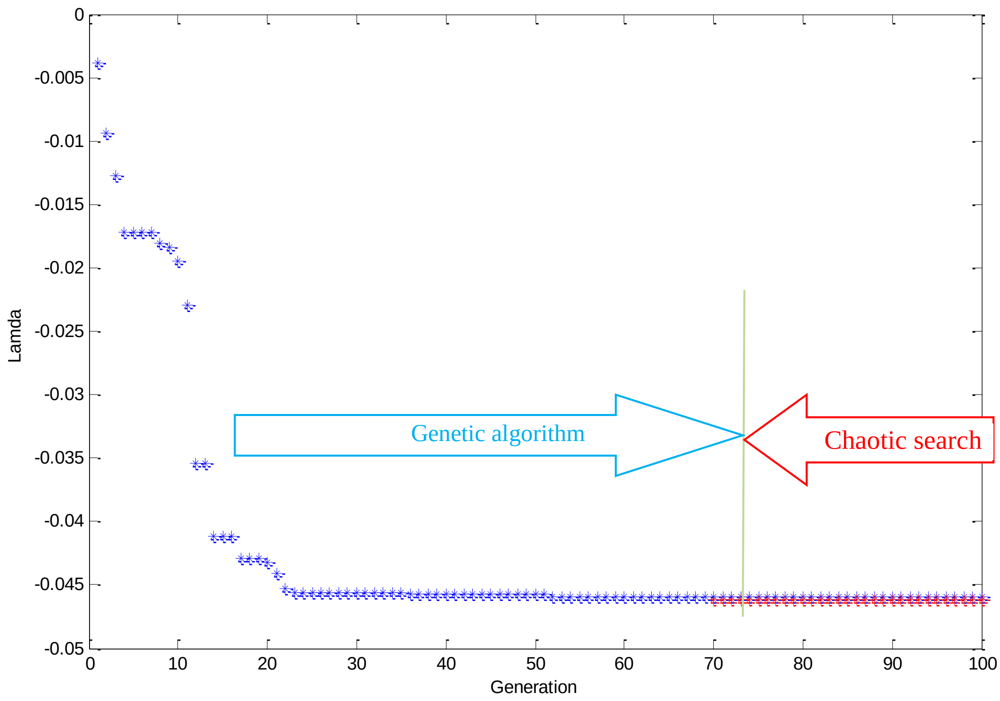

Fig. 15. Convergence analysis for real application

In general, this real life application has carried out its aims by forming mathematically new modified membership function (parabolic function) and in implementation it in a limited resources production planning problem. Based on the results analysis of bi-objective real life resource production planning application with minimizing harmful pollution substance and maximizing revenue, the following points are drawn:

1. The proposed mathematical model can be applied to higher dimension problem with many objectives by incorporating only one additional nonlinear constraint for each additional objective function.
2. The proposed model using modified membership function can be extended to any real application in any fields of engineering, and science, with no modifications.
3. Investigation of results refer to that the total income and the total hurtful pollution substance in the proposed model are increased by 3% and decreased by 4% respectively as compared to maximum membership values in the fuzzy decision with linear member ship function (Linear Programming Model) [43].

7. CONVERGENCE ANALYSIS OF THE SUGGESTED METHOD

To compute the computational time comparison and to monitor the convergence behavior of the proposed algorithm, this analysis is presented. On the first hand, to make comparison in the view of the speed of the convergence, we must define how to measure the execution period. The number of generation (iterations) cannot be applicable as measurement of execution period, and this is due to different algorithms execute different procedure of works in their inner loops and have different parameters and different operators (population size, crossover probability, mutation probability,…etc.), in our comparison, the number of fitness evaluations (objective function) (FEs) was implemented as a measure of the executed computational time for each algorithm, which can better reflect its real running time. On the other hand, the search space was shrunken after phase I concentrating the optimal solution region. So the proposed algorithm converges in accelerated manner to the optimal solution. In addition, the suggested hybrid method enables us to come closely to the optimal solution than the previous techniques based on evolutionary algorithm. In brief, this proposed algorithm in phase I have capability to adjust) its searching region (to shrunk the search space) for the second phase Table 3 gives the percentage saving of time computation; the obtained results declare that using the proposed approach saving around 30% as an average. Tables 3 also declare that the values reported by SCGA gives a valuable decrease in execution period compared to the proposed approach without Sinusoidal chaotic. Finally, the main features of some literature algorithms were described in Table 4. It is concluded that the proposed algorithm exploits the advantages of chaotic mapping and global search capability of GAs for rapidly convergence to the optimal solution.

Table 4. Comparing some optimization algorithm

Features	Classical methods	Local search methods	Evolutionary algorithms	Chaotic methods	Proposed hybrid algorithm
Highly computational time	×	×	✓	×	×
Sensitivity to initial conditions	✓	✓	✓	×	×
Initial parameters requirement	×	×	✓	×	✓
Global search ability	×	×	✓	✓	✓
Local search capability	✓	✓	×	×	✓

The most effective reason of decreasing execution period of executing the suggested method if compared with the other algorithms is that the proposed hybrid algorithm keep away from the formal seeking in the universe of the problem and to concentrate the search in a specified local region.

8. CONCLUSION

This research presents a hybrid genetic algorithm- Sinusoidal chaotic Map to solve general constrained NLP. Regrettably, detecting a universal optimum solution has no known method to the general constrained NLP. The proposed algorithm is consists of a classical genetic algorithm coupled with a Sinusoidal chaotic Map based local search. It has been concluded that coupling with chaotic mapping save executing time, which can better reflect its real running period and accelerate convergence of the algorithm to the global solution. It has been also known that, the sensibility to the initial state is one of the most important characters of chaotic mapping. This feature ensures that there are no two identical new solutions obtained which ensures the population diversity and improve the global searching capability by escaping the local solutions and prevent to get stuck in local optima. Several problems from the literature enabled us to measure our results with respect to other known algorithms. Via the numerical analysis, we can conclude that our proposed combined algorithm is very robust and give very accurate final solution. The basic characteristics of the suggested hybrid technique could be recorded as written in the following points.

1. The proposed algorithm has been robustly applied to solve the constrained NLP with different type of constraint.
2. The proposed algorithm is efficient and robust for solving nonconvex, discontinuous and non-differentiable optimization problems
3. On the basis of the real life application, it was concluded that the proposed hybrid algorithm can provide a true optimal solution by considering conflicting bi-objective functions.

For future work, we suggest to apply the proposed algorithm on highly dimension real-world applications.

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