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Elitist Genetic Algorithm Performance on the Uniform Circular Antenna Array Pattern Synthesis Problem

***Abstract**. In this paper, the impacts of elitism rate on the Genetic Algorithm (GA) performance for the Uniform Circular Antenna Array Pattern Synthesis Problem are investigated. For this purpose, a circular antenna array with uniformly spaced isotropic elements having identical excitation amplitudes is used as a model. Unlike the classical GA, we use a GA structure having an elitist population update approach for improved GA performance. In the elitist approach, a certain ratio of the population (i.e. the fittest individuals) is directly transferred to the next generation.*

***Streszczenie.** W artykule zaprezentowano wykorzystanie algorytmu genetycznego do analizy jednorodnej kołowej matrycy anten. W tym celu jako model użyto anteny z regularnie rozmieszczonymi elementami mającymi tę samą amplitudę pobudzania. Użyto zmodyfikowanego algorytmu genetycznego z populacją elistyczną. (**Synteza kołowej anteny matrycowej z wykorzystaniem algorytmu genetycznego**)*

Keywords: Circular antenna array, elitist genetic algorithm, elitism rate, pattern synthesis.
Słowa kluczowe: antenna kołowa, algorytm genetyczny, synteza.

Introduction

Genetic algorithm (GA), differing from conventional search techniques, is a probabilistic search method based on the principles of Darwin's natural selection and evolution theory. So far, GA has efficiently been used for the solution of combinatorial optimization problems [1-4]. In this context, it has been quite successful in many engineering applications. Additionally, it has also been applied to certain problems in the electromagnetic theory. Antenna array synthesis problem constitutes a major portion of such applications.

Antenna array synthesis problem, which is one of the popular research topics in electromagnetics, requires nothing but to obtain the desired pattern (generally which cannot be achieved with a single antenna) with minimum error. In such a problem, electrical specifications and geometrical placements of the array elements are important.

Generally, the main expectations of the designer from the antenna arrays are: radiation pattern consisting of a narrow main beam in the desired direction, and low-level side lobes. Many different antenna array configurations might be constructed; but due to their simplicity the most widely applied configurations are linear, planar and circular arrays [5-6].

In the literature, there are studies on antenna array design, synthesis and pattern forming using optimization methods such as genetic algorithm and particle swarm optimization [7-10]. In [7] and [8], the side lobe reduction on circular antenna arrays was performed by means of the genetic algorithm and particle swarm optimization. In [9], radiation pattern synthesis was performed through a hybrid real coded GA algorithm consisting of simplified quadratic interpolation.

In our previous research [10], the impacts of the mutation rate and the crossover position on the GA performance were investigated via the uniform circular antenna array pattern synthesis problem. This time, we aim to analyse the elitist GA performance, where the ideal elitism rate will be investigated.

There are studies on the elitist GA in the literature [11-20].In [11], a new technique called "adaptive elitist-population search method" was introduced. It is based on the concept of adaptively adjusting the population size according to the individuals' dissimilarities and a novel direction dependent elitist genetic operator.

Ref. [12] demonstrates the possibilities of adapting elitism-based GA models in order to optimize the high volume fly ash concrete mixes.

Ref. [13] presents a new permutation-based elitist genetic algorithm using serial schedule generation scheme for solution of a large-sized multiple-resource constrained project scheduling problem.

In [14], a method combining the new Ranked based Roulette Wheel selection algorithm with Pareto-based population ranking Algorithm is proposed. Two elitism-based compact genetic algorithms, "persistent elitist compact genetic algorithm" and "nonpersistent elitist compact genetic algorithm" were described in [15].

Ref. [16] introduces a new technique called "adaptive elitist population search method", which allows extension of unimodal function optimization methods to locate all optima of multimodal problems in an efficient manner.

In [17], a replacement strategy for steady-state genetic algorithms considering two features of the candidate chromosome to be included into the population: a measure of the contribution of diversity to the population and the fitness function.

In [18], the relationship between the elitist genetic algorithm performance and algorithm termination criteria was examined.

Ref. [19] proposes a hybrid algorithm consisting of hypermutation and elitist strategies for computed aided analog circuit design synthesis problems.

Ref [20] presents a new cross-layer resource allocation model for multiuser packet-based Orthogonal Frequency Division Multiplexing (OFDM) systems proposing an elitist selection adaptive genetic algorithm.

Unlike the other studies in the literature, we investigated methods for performance improvement in this study in order to obtain a desired pattern of circular antenna array with elitist GA. For this purpose, different elitism approaches are tried to solve Uniform Circular Antenna Array Pattern Synthesis Problem.

The effects of elitism have so far been studied many times. In our opinion, the originality of this study comes from the following reason: Even though in some previous publications (such as [11-12]) it has been mentioned that elitist GA provide better performance, to our knowledge, there exists no publication explicitly investigating how to change or manipulate the elitism rate ideally. In addition, to the best of our knowledge, there is no study about elitist GA performance on antenna array synthesis problem.

In this paper, in Section 2, basic definitions of GAs are revisited briefly. In Section 3, formulations regarding the circular antenna arrays and the relevant synthesis problem are presented. In Section 4, material and method are presented together with the obtained results and relevant discussions. Section 5 concludes the paper with some remarks.

Genetic Algorithm (GA)

Genetic Algorithm (GA) was first introduced in 1975 by Holland [1]. Dense usage of this algorithm has been realized especially after Goldberg's studies [2]. Genetic Algorithm provides the necessary solution yielding the global minimum or maximum values of multidimensional and complicated functions [2-3]. They are used in widely for the solution of the problems, which are considered very difficult for conventional optimization methods.

GA simulates the survival of the fittest among individuals over consecutive generations throughout the solution of a problem. Each generation consists of a population of character (usually binary) strings that are analogous to the chromosomes. Each individual represents a point in the search space and a solution candidate. The individuals in the population are then exposed to the process of evolution.

Genes from good individuals propagate throughout the population. Thus, each successive generation will literally become more suited to their environment. In the optimization terminology, this corresponds to the situation that newer generations have better fitness values [1-4]. Fig.1 presents the general structure of the conventional/classical Genetic Algorithm.

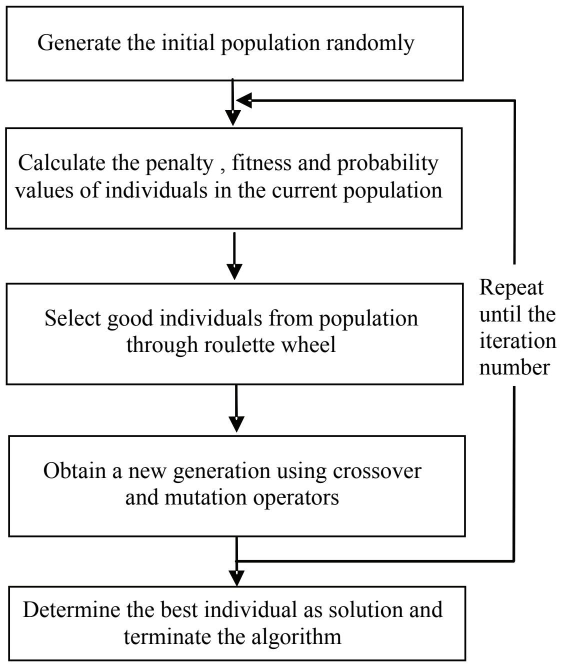

Fig.1. General structure of the classical genetic algorithm.

Circular Antenna Arrays

Antenna arrays are antenna systems, which are created by combining different or similar antennas in different forms. Antenna arrays are used in order to provide the desired specifications such as low-level side lobe, narrow main lobe and high directivity [5-6].

Furthermore, thanks to adding together power of the elements in array, high-power radiation pattern is achieved and without requiring mechanical movement, main beam can be steered to a desired direction [5-6]. This yields a very wide application spectrum for the antenna arrays. Arrays may be located different geometric shapes. If elements of array are located on a circle, this type of array is called the Circular Antenna Array as seen in Fig.2.

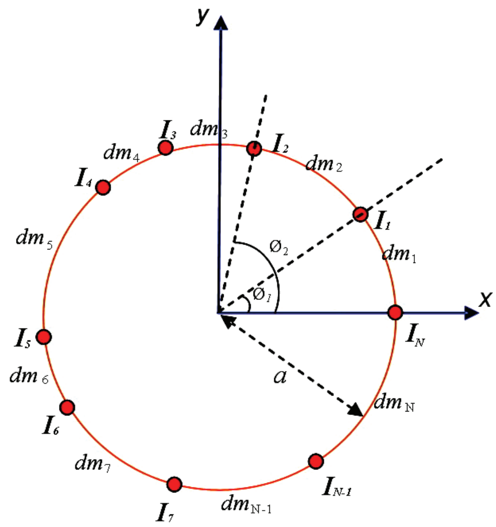

Fig.2. Geometry of a uniform circular antenna array with N isotropic elements.

Radiation pattern of the circular antenna array consisting of N isotropic elements can be expressed by means of the array factor. The array factor of circular antenna array formulated as follows [8]:

(1) $$AF(\phi, I, dm) = \sum_{n=1}^{N} I_n e^{jka[\cos(\phi-\phi_n)-\cos(\phi_0-\phi_n)]}$$

Here, AF is the array factor, N is the number of elements in the array, I_n is the excitation amplitude of the nth element, a is the radius of the circle, $k=2\pi/\lambda$ is the wavenumber, ϕ_0 is angle of direction of the main beam, ϕ_n is the angular position of the nth element with respect to ϕ_0. ka and ϕ_n are given by:

(2) $$ka = \frac{2\pi a}{\lambda} = \sum_{i=1}^{N} dm_i$$

(3) $$\phi_n = \frac{2\pi \sum_{i=1}^{n} dm_i}{\sum_{i=1}^{N} dm_i}$$

Material and Method

In our study, a circular antenna array with uniformly spaced isotropic 8 elements having identical excitation amplitudes is used as a model.

For this purpose, radiation pattern of a circular antenna array, for which:

- the angle of direction for the main beam is equal to zero degree;
- the angular positions of the elements (ϕ_n) are 22.5, 67.5, 112.5, 157.5, 202.5, 247.5, 292.5 and 337.5°; and
- the radius of the circle is 20 cm,

is determined as reference. The Half Power Beam Width of the reference pattern is chosen to be 56°, and the operating frequency is chosen to be 750 MHz.

To obtain the desired pattern through genetic algorithm, an initial population consisting of 60 individuals is created. Then, angular positions of 8 elements are converted to binary codes. Afterwards, the created population is subjected to the genetic algorithm operators: selection, crossover and mutation.

Throughout the study; all comparisons in all experiments were performed by considering independent executions of each GA scheme in order to eliminate the "chance factor" and to be able to perform a fair comparison. Table 1 lists the parameter setup used throughout the experiments in this study.

Table 1. Parameter values used in the genetic algorithm and the example problem.

Parameter	Values used in GA
Number of individuals in the population	60
Number of elements in the array	8
Number of iterations (generations)	1000
Crossover rate	0.2
Mutation rate	0.01
Number of independent executions	100

In the implementation, the radiation diagram is divided into 360 equal parts in ($-\pi$, π) radians. Thus, a sensitivity of one-degree is achieved. GA is implemented in MATLAB 7.3.0, but no third party tool or another standard product or library (such as MATLAB Genetic Algorithm Toolbox) is used. The main reason for this is to preserve the flexibility to modify the GA architecture in our ongoing/future studies in order to investigate further performance improvement possibilities.

In classical or conventional GA, GA operators such as selection, crossover and mutation are applied to all individuals in the population. In this study, we tried to improve genetic algorithm performance using the elitist population structure. In elitist population method, the best individuals of current population in a certain ratio are directly transferred to the next generation. Hence, throughout this process, the transfer of good individuals to the next generation is guaranteed.

In order to determine the ideal elitism rate, the performances of different elitism rate changing schemes are examined. For this purpose, primarily, "fixed elitism rate" is tested. Next, "increasing" and "decreasing elitism rates" are tested. Results show that increasing elitism rate methods cannot improve the GA performance. For this reason, only one increasing elitism rate is presented. In the following equations, r_e represents the elitism rate, n_i represents the number of iteration, and f_{ave} represents the average fitness value of population. We use five different elitism rate schemes. These are:

1st Scheme: Constant elitism rate

In this scheme, the elitism rate is kept fixed for all iterations.

(4) $$r_e = 0.2$$

2nd Scheme: Increasing elitism rate throughout the iterations

In this scheme, the elitism rate increases depending on the number of iteration as in the following equation:

(5) $$r_e = 0.1 + (n_i \times 2 \times 10^{-4})$$

In Figure 3, variation of the elitism rate along the iterations is presented.

3rd Scheme: Decreasing elitism rate throughout the iterations

In this scheme, the elitism rate decreases depending on the iteration number as in the following equation.

(6) $$r_e = 0.25 - (0.01 \times n_i^{0.4})$$

In Figure 4, variation of the elitism rate along the iterations is presented.

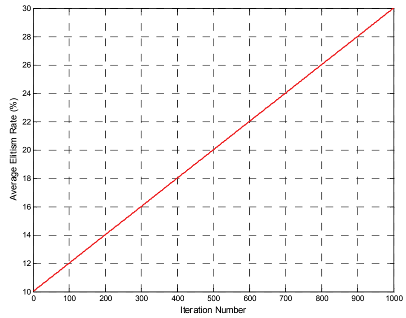

Fig.3. Increasing elitism rate throughout the iterations.

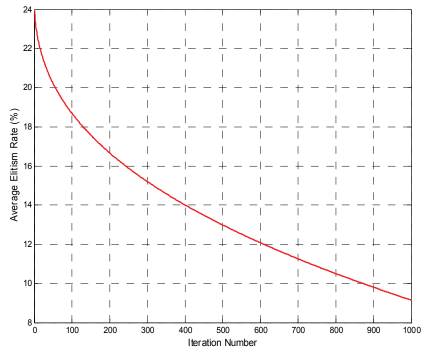

Fig.4. Decreasing elitism rate throughout the iterations.

4th Scheme: Partial fixed elitism rate

In this scheme, the elitism rate is fixed (20%) in the first half of iteration number and elitism rate equal to zero in the second half of iteration number.

In Figure 5, variation of the elitism rate along the iterations is presented.

5th Scheme: Decreasing elitism rate depending on the average fitness value of population (adaptive elitism)

In this scheme, the elitism rate decreases depending on the average fitness value of population as in the following equation:

(7) $$r_e = 0.25 - (5 \times f_{ave})$$

In Figure 6, variation of the elitism rate along the iterations is presented.

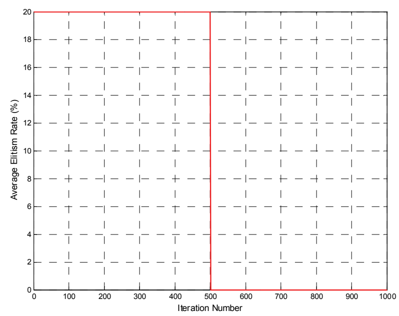

Fig.5. Partial fixed elitism rate.

For reference throughout the performance comparisons, the average fitness values of population obtained by classical GA without elitism is presented in Figure 7.

Average fitness values belonging to all proposed and tested elitism schemes are presented in Figure 8. These results show that partial fixed elitism rate (4th scheme) outperforms to the other schemes. The desired radiation pattern together with the obtained radiation pattern by means of 4th scheme can be seen in Fig. 9.

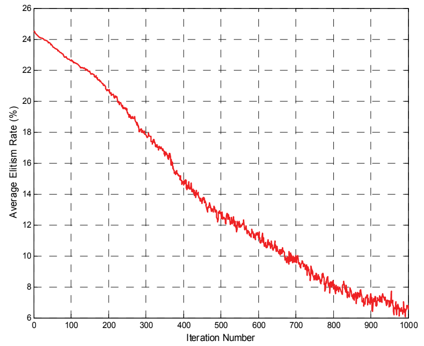

Fig.6. Decreasing elitism rate (depending on the average fitness value of population).

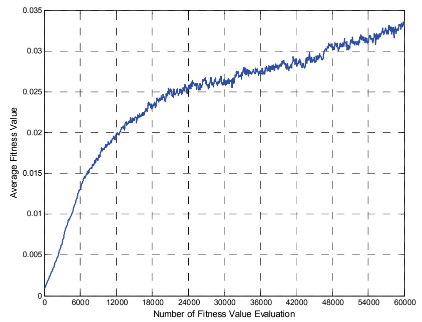

Fig.7. Average fitness values of population obtained by classical GA.

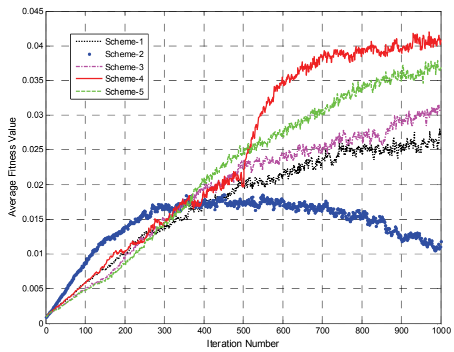

Fig.8. Average fitness values of population (different elitisim rate schemes).

The most important contribution of elitist GA is reduction in the number of fitness value evaluations throughout the solution. This contribution provides time-saving in the solution of problems. In our study, thanks to the Partial Fixed Elitism Rate (4th scheme), 10% reduction is achieved concerning the number of fitness value evaluations. In addition to this success, 23% performance improvement (solution accuracy) is achieved compared to the classical GA. The average fitness values of the population (obtained by Partial Fixed Elitism Rate Method and Classical GA) versus the number of fitness value evaluations are seen in Figure 10. It can be seen that about 23% more average fitness values are achieved after 10% less fitness function evaluations.

Conclusions

This paper discussed how to manipulate the elitism rate in an elitist genetic algorithm for performance improve genetic algorithm via the uniform circular antenna array pattern synthesis problem. For this purpose, a circular antenna array with uniformly spaced isotropic elements having identical excitation amplitudes is used as a model. Thanks to elitist population approach, the best individuals of current population in a certain ratio are directly transferred to the next generation.

Regarding the elitism rate, the following observations can be made: The selection, crossover and mutation operators may cause corruption of the genes of individuals. This effect may reduce the fitness values of individuals. By using the elitist GA, this negative effect can be eliminated. However, to obtain the best GA performance, the elitism rate should be manipulated in an intelligent manner. Our study shows that for this antenna array synthesis problem, Partial Fixed Elitism Rate (in which the elitism rate is fixed (20%) in the first phase of the algorithm; and equal to zero in the second phase of the algorithm) provides the best performance compared to others. This phenomenon can be explained as follows: in the early generations, the overall population is of relatively low quality; and hence, elitism is a performance-improving factor, which increases the rate of good individuals in next population. But when the population gets qualified, elitism starts to cause saturation, even distraction in the population. Therefore, after a certain iteration number, elitism rate should be reduced.

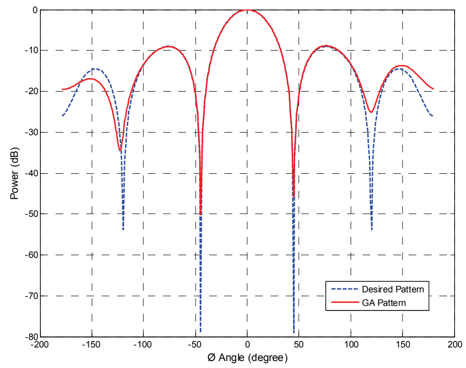

Fig.9. The comparison of desired and obtained radiation patterns.

Thanks to Partial Fixed Elitism Rate, 10% fitness value evaluation reduction and 23% solution accuracy performance improvement is obtained compared to the classical GA. This advantage of the Partial Fixed Elitism Rate approach would be much more appreciated for the problems in which the computational cost of fitness function evaluations are quite high.

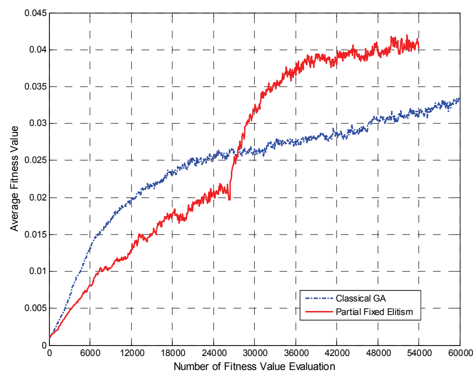

Fig.10. Average fitness values of population (obtained by Partial Fixed Elitism Rate and classical GA) versus the number of fitness function/value evaluations.

These results are valid for this particular problem only. Generalization and direct application of these results to all problems would be incorrect. As a future work, similar analyses in electromagnetics will be performed using other evolutionary algorithms such as the Differential Evolution Algorithm.

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