Improved Adaptive Particle Swarm Optimization for Wide Null Steering of a Linear Phased Array antenna

Ghada Shaban M., H. A. Mohamed, Hanan Kamal

Abstract— this work is concerned with using a methodology for eliminating the effect of unwanted interference in a certain direction applied to the radiation pattern of a linear array antenna. An efficient method based on Particle Swarm Optimization is used .The amplitude of the elements in the linear array antenna is optimized in order to achieve nulls at the positions of the interference. The proposed Improved Adaptive Particle Swarm Optimization (IAPSO) is an efficient method applied for optimization. The Dolph-Chebyshev array is used to show the success of obtaining nulls at certain identified positions where interference occurs. The results shows the efficiency of the proposed technique in achieving perfect wide nulls with depth of -75 db using 1700 iterations as the maximum number of iterations. Sensitivity and robustness of the proposed algorithm are tested at different array antenna systems with different properties which prove the effectiveness of the technique proposed in achieving the property of interference cancellation. Further, the side lobe levels and the main beam width are preserved at their original levels of the main signal without being increased.

Index Terms— Particle Swarm Optimization (PSO), Improved Adaptive Particle Swarm Optimization (IAPSO), Enhanced Particle Swarm Optimization (EPSO), null placement, linear antenna array, side lobe level, wide nulls and Uniform Linear Array(ULA).

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1 INTRODUCTION

Electromagnetic systems are used widely nowadays. The pollution of the electromagnetic environment was the main problem that prompted the study of the nullifying of the radiation patterns techniques. These techniques are very important to be applied in various applications such as radar, sonar and other communication systems such as satellite [1]. They help to minimize the degradation in the signal to noise ratio that happens due to the interference. The main concern during the process of data transfer is the conformity of the received signal with the transmitted signal. This concept is very challenging due to the fact of exposing the transmitted signal to many factors that may result in either changing the data structure or missing some of this data. Those factors can be intended or due to simple distortion and noise in the environment and can also be due to device malfunctions. A lot of research has been made on the change of certain signal positions into nulls. Some conventional methods where used for achieving nulls at certain positions. The wide nulls can be done by making multiple adjacent nulls in the radiation pattern [2]. Using the evolutionary optimization techniques are the most efficient in forming these wide nulls. Wide nulls forming are achieved by controlling the array weights called the excitation coefficients.

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The nulling methods are generally based on controlling the complex weights (both the amplitude and the phase), the amplitude only, the phase-only, and the position only of the array elements. Interference suppression with complex weights is the most efficient because it has greater degrees of freedom for the solution space [3, 4]. However, it is a very expensive method due to the high cost of both phase shifters and variable attenuators for each element of the array. Moreover, as the number of elements of the array increases, the computational time of finding the values of the elements amplitude and phase will increase. The amplitude only control uses a set of variable attenuators to adjust the element amplitudes. If the element amplitudes possess even symmetry about the center of the array, the number of attenuators and the computational time are halved. The nulls are achieved by using non uniform excitation coefficients to impose the nulls at certain directions which are achieved by the optimization technique used.

The disadvantages of the classical optimization techniques made the researches move towards using the evolutionary optimization techniques that are based upon computational intelligence methodology. A lot of evolutionary algorithms have been used before in different optimization problems. Examples of these algorithms are the Genetic Algorithms [5], the bee colony [6], the ant colony [7], the backtracking algorithm and clonal selection [8]. The used optimization technique in this paper is the Particle Swarm Optimization. It was found to have a lot of advantages over other evolutionary techniques such as it does not have overlapping and mutation calculation.

The search can be carried out by the speed of the particle so only the most optimist particle can transmit information onto the other particles, and the speed of the researching is very

fast, also The calculation in PSO is very simple. Compared with the other developing calculations, it occupies the bigger optimization ability and it can be completed easily. An improved PSO was used that made the results enhanced in the null depth of the achieved nulls in the direction of the interference. These results were compared with the results of the previous research done in the same field [9] to add more enhancement to the achieved results before which will be discussed later.

In this paper, a linear symmetric array antenna with equally spaced elements is considered. The optimal values of the excitation coefficients are obtained while keeping the phase difference between any two elements equals zero. Wide nulls are achieved by the optimization of only the element amplitudes of linear antenna arrays using an Improved Adaptive Particle Swarm Optimization (IAPSO). This IAPSO works by having a Cauchy mutation [10] on both the cognitive and social parameters. This solves the problem of the particles oscillation in PSO between their previous best position and the global best position found by all particles before it converges. This prevents the swarm's particles from being stuck at a local best position. So, the ability of the global search is very much enhanced after the use of this modification. Simple Particle Swarm Optimization [11], Enhanced Particle Swarm Optimization (EPSO) [9] and Novel Particle Swarm Optimization [12] used before where methods of modification for the simple PSO that were used in optimizing the same problem. The superiority of the used IAPSO is shown in this article. The design of the Dolph-Chebyshev array was successfully done using the MATLAB 2011 program. The initial excitation coefficients of this design were the input to the simulated program of IAPSO in MATLAB to get the optimized excitation coefficients

The article is arranged as follows: In Section 2, the linear array pattern used is defined. Its geometry, structure and the design equations used. Section 3 gives a brief description of the classical PSO, EPSO and the new IAPSO. In Section 4, simulated results of the IAPSO are shown along with the comparison results of the IAPSO and the EPSO and the classical PSO. Section 5, shows the Sensitivity Analysis of the used IAPSO algorithm to show its robustness when using different array antenna systems with different properties and finally Section 6 concludes the article.

2. LINEAR ARRAY DESIGN

A classical Chebyshev linear array design is used. The Conventional Dolph-Chebyshev arrays were introduced by Dolph in 1946. They are based on mapping the Chebyshev polynomial into the array's space factor. These polynomials are originated as possible solutions of a second order ordinary differential equation with variable coefficients. Dolph stated that for a desired Side Lobe Ratio (SLR), the Chebyshev polynomial of order (L-1) can be mapped into the space factor of a Uniform Linear Array (ULA) of L elements. This results in an equiripple Side Lobe Levels and a main beam that is the narrowest

possible. The Chebyshev array offers improvements over similar pre-existing arrays in terms of directivity and half power beam width. These arrays can have different number of elements, different side lobe levels, but the same inter-element spacing. This design guarantees the controllability of the maximal side lobe level (MSLL). Using the Chebyshev polynomials, it is possible to design arrays with specific side lobe characteristics. Namely, all side lobes can be designed at some prescribed level.

The Chebyshev array has so many areas of application. They can be used widely such as in radar, sonar and different communication systems according to their frequency of operation. Since the Chebyshev array gives a narrow beam width, it can focus a frequency range in a smaller area. Furthermore, the relationship between the directivity and side lobe level for these arrays is optimum in that for a specified side lobe level the beam width is the smallest and alternatively, for a given beam width the side lobe level is the lowest [13]. Placing nulls in the antenna radiation pattern will be a complex process as this will alter the trade-off and introduce deterioration in side lobe level or directivity.

One of the most eminent methods used to equate the sidelobes arising in the radiation pattern of antenna arrays is to utilize a set of polynomials referred to as Chebyshev polynomials. These polynomials oscillate with unit amplitude and become monotonically increasing or decreasing, depending on their order, outside this range. This property of Chebyshev polynomials enabled Dolph to use them to design an equiripple radiation pattern [14].

A linear antenna array is designed with 2N isotropic elements placed symmetrically along the Z-axis with equal inter-element spacing d ($d = \lambda/2$), and N elements are placed on each side of the origin as shown in figure 1. The array factor for this structure is expressed as

$$AF(\psi) = \sum_{n=-N}^{N} I_n \, e^{jd_n\psi} \qquad (1)$$

Where $I_n = I_n^{Re} + jI_n^{Im}$ are the complex excitation coefficients of each element in the array, (n= -N,…,-2,-1,1,2,...N), ψ=k.sin(θ) and k is the wave number. Therefore, the real and imaginary parts of the array factor are

$$Re\{AF(\psi)\} = \sum_{n=-N}^{N} I_n^{Re} \cos(d_n\psi) - I_n^{Im} \sin(d_n\psi) \qquad (2)$$

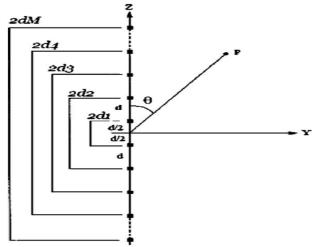$$Im\{AF(\psi)\} = \sum_{n=-N}^{N} I_n^{Im} \cos(d_n\psi) + I_n^{Re} \sin(d_n\psi) \qquad (3)$$

Fig. 1. Linear antenna array designs with 2N elements of equal inter elements spacing [12].

The case considered in this paper for the current coefficients of the array elements is the amplitude only control. In this case, $I_{-n}^{Re} = I_n^{Re}$, because the excitation coefficients are real and symmetric around the center of the array, this gives a pattern which is symmetrical about the main beam direction ($\theta_m = 0$). Since $I_n^{Im} = 0$ and $\sin(-d_n\psi) = -\sin(d_n\psi)$ then the imaginary part of AF in (3) equals 0. While, the real array factor (2) is reduced as following

$$AF(\psi) = 2\sum_{n=1}^{N} I_n^{Re} . \cos(d_n\psi) \qquad (4)$$

3. PARTICLE SWARM OPTIMIZATION TECHNIQUES

3.1 Simple Particle Swarm Optimization

Particle Swarm Optimization is a swarm intelligence method for global optimization [15]. Each individual, named particle, of the population, called swarm, adjusts its trajectory toward its own previous best position, and toward the previous best position attained by any member of its topological neighborhood. The basic PSO algorithm consists of three steps:

(1) The positions, $x^i(k)$ and velocities, $v^i(k)$ of the initial population of particles are randomly generated for the ith particle at time k. Where i is the current particle number in the swam, $i \in \{1, 2...., S\}$ and S is the swarm size.

(2) Update velocities of all particles at time k +1 as follows:

$$v^i(k+1) = w.v^i(k) + c_1.r_1(p^i(k) - x^i(k)) + c_2.r_2(p^g(k) - x^i(k)) \qquad (5)$$

Where, r_1 and r_2 are uniformly distributed random variables in [0,1] range. The fitness function values determines which particle has the best position value $p^i(k)$ over the current swarm, and also updates the global best position $p^g(k)$ for the current and all the previous swarm moves. The three terms in the equation are presenting the current motion, particle own memory, and swarm influence. These parameters are summed with three weights, namely, inertia factor,w, self confidence factor, c_1, and swarm confidence factor, c_2,respectively. Velocity updates here

are influenced by both the best global solution and the best local solution in the current population.

(3) The position of each particle is updated using its velocity vector at time k +1 as:

$$x^i(k+1) = x^i(k) + v^i(k+1) \qquad (6)$$

The three steps of velocity update, position update, and fitness calculations are repeated until a desired convergence criterion is met.

From the mathematic theoretical analysis of the trajectory of a PSO particle [16], the trajectory of a given particle $x^i(k)$ will "fly" to its local best position $p^i(k)$ and then to the global best position $p^g(k)$. This mechanism of information sharing makes the PSO has a very fast convergence speed. However, PSO cannot always guarantee to find the minimal value of a function. Usually, the particles converge to a local optimum. Once the particles are trapped in a local optimum, at which $p^i(k)$ is assumed to be the same as $p^g(k)$, all the particles converge at $p^g(k)$. So, the velocity equation is changed to:

$$v^i(k+1) = w.v^i(k) \qquad (7)$$

When the iterations number increases, the velocity of the particles $v^i(k)$ will be close to zero due to the fact of that $0 \le w < 1$. This makes the positions of the particles unchanged, so the PSO will not have the capability of jumping out of the local optimum.

3.2 Enhanced Particle Swarm Optimization (EPSO)

To overcome this drawback in the simple PSO , a new enhancement was done added to it to get the EPSO algorithm [9]. A modification was added to the velocity equation as follows:

$$v^i(k+1) = w.v^i(k) + c_1.r_1.(p^i(k) - x^i(k)) + c_2.r_2.(p^g(k) - x^i(k)) + c_3.r_3.(p_{fdr}^i(k) - x^i(k)) + c_4.r_4.(p_{fdr}^g - x^i(k)) \qquad (8)$$

Where, c_3 and c_4 are acceleration constants, r_3 and r_4 are uniformly distributed random variables in [0, 1] range. $p_{fdr}^i(k)$ and p_{fdr}^g are two new local and global candidate positions that are selected by locating the individual with minimum fitness to distance ratio (FDR) over all particles in the swarm.

This technique was able to solve the problem of being trapped in a local optimum and to enhance the optimization solution. Its result was simulated and verified to reach a null depth of -67 dB.

3.3 Improved Adaptive Particle Swarm Optimization (IAPSO)

For the Improved Adaptive Particle Swarm Optimization technique used in this paper, the problem of the signal interference will be solved using a new algorithm which is applied for the first time for this problem.

Adaptive wide nulling for broad-band interference suppression is achieved by perturbing the current weights of array elements. Simultaneously, it is always desirable to keep the main beam width (directivity) and the peak SLL within a certain given level. This is realized by solving minmax optimization problem that is subject to three constrains for SLL limits, the prescribed depth of the wide null and main beam acceptable broadening. The problem can be described as:
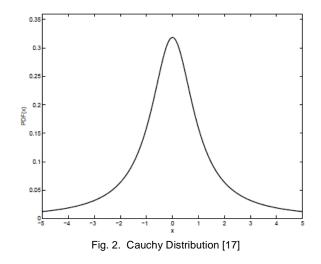
$$min_{I_n} \in c\{max_{\theta_{min} \leq \theta \leq \theta_{max}}|AF(I_n, \theta, d_n)|\} \qquad (9)$$

s.t. $MSL_1 \leq SLL$ & $MSL_2 \leq$ Wide null depth & $\Delta BW \leq \delta$

Where $AF(I_n, \theta, d_n)$ is described as the array factor as a function of current coefficients (I_n), the angle with respect to the direction of the array (θ) and the distance between the array elements (d_n). θ_{min} and θ_{max} are the minimum and maximum boundries of the elevation angles for the prescribed wide null. S.t. means subject to constraint, C is the set of all vectors with complex components. The complex vector I_n is the optimization parameters. SLL is the pattern peak side lobe level, MSL_1 is the prescribed value for SLL excluding the main beam band, MSL_2 is the peak SLL in the region of wide null and ΔBW and δ are the change and the maximum allowable change in the main beam width respectively.

To overcome the weakness of the PSO and improve the result of the EPSO, the IAPSO was used. This algorithm is mainly based on incorporating the Cauchy mutation into the PSO. That is implementing a part of the genetic algorithm which is the mutation into the PSO. This combination between the genetic and the particle swarm makes a hybrid algorithm that improves the results of the optimization. c_1, c_2 are taking random values in the range from [1:4] as the values initially used in this algorithm. Velocity and position equations (5) and (6) are used. The Cauchy mutation here is applied to the values of both the self confidence and the swarm confidence factors c_1 and c_2 as shown

$$C_{1i} = c_{1i} + \delta \qquad (10)$$
$$C_{2i} = c_{2i} + \delta_i \qquad (11)$$

Where δ and δ_i denotes Cauchy random numbers.

Figure 2, shows the Cauchy distribution. Different values for C_1 and C_2 are obtained. These values are then used in the velocity update equation which hence updates the position obtaining a new particle's position. This new mutated particle is hence used in the search space to find another solution and hence solves the problem of the PSO trapping at a local optimum. Since the expectation of the Cauchy does not exist, the variance of the Cauchy distribution is infinite so that the Cauchy mutation could make the particle have a long jump. By adding the update equations (10) and (11), the IAPSO greatly increases the probability of escaping from a local optimum.

Fig. 2. Cauchy Distribution [17]

The objective function was developed as follows:

$$\text{Fitness} = \sum_{\theta=-\pi/2}^{\pi/2}(|W(\theta).AF_O(\psi) - AF_i(\psi)|) + C(\theta) \qquad (12)$$

Where $AF_i(\psi)$ is the initial radiation pattern of the Chebyshev, $w_{null}(\theta)$ is a function that specifies the wide nulls locations and $AF_O(\psi)$ is the optimized radiation pattern. The objective function is formed by adding two terms. The first term is the summation (over all sample points) of the squared value for the difference between the desired and the initial array factors. The second term is function that related to the SLL and the depth of the null constraints. $C(\theta)$ is a term added to make the SLL at the desired level with achieving the required null depth.

3.3.1 The proposed Algorithm

(Step 1) Data preparation: Calculation of the initial amplitude excitation coefficients of the Dolph Cheby-shev array using a formulated MATLAB code for the array design.

(Step 2) Particle initialization and PSO parameter settings: generate the initial particles and set the parameters including number of particles, number of maximum iterations, the inertia weight, the velocity and position equations (5) and (6), the initial self and swarm confidence factors and the fitness function used.

(Step 3)Fitness evaluation: calculate the fitness for each particle fitness(i).

(Step 4) Local and Global best positions calculations:
If (fitness(i) $\leq p^i(k)$) then set $p^i(k) =$ fitness(i).if ($p^i(k) \leq p^g(k)$) then set $p^g(k) = p^i(k)$.

(Step 5) Adopt the Cauchy mutation operator to manipulate both C_{1i} and C_{2i}.

(Step 6) Update the particle's velocity again using the mutated C_{1i} and C_{2i}.

(Step 7) Update the particle's position and form new particle swarms.

(Step 8) Compute the fitness function value of each particle in accordance to the updated position.

(Step 9) Compare the current optimal particle with last generational optimal particle and update global and personal best.

(Step 10)Stop Condition checking: This is the condition under which the search process will terminate. In this study, the

search will terminate if the following criteria is satisfied: The number of iterations reaches the maximum allowable number. If the termination criterion is satisfied, then stop, or else go to step 3.

A computer program in MATLAB is developed to optimize the array factor of the antenna array described for the amplitude only control using IAPSO. The results are described in the next section.

4. SIMULATION RESULTS

4.1 IAPSO simulation results

For all the subsequent results shown, the optimization process will be initialized by a classical chebyshev design of 20-element linear array with $\lambda/2$ equal inter-element spacing and the SLL do not exceed -30 db.

The prescribed IAPSO is applied which is successfully able to enhance the optimization results than the previous used EPSO and the simple PSO algorithms. The prescribed nulls were depicted in the radiation pattern in the band [10, 30] degrees. Since amplitude only control is used here, a symmetric image wide null is observed at the sector [-10,-30]. The parameters used by the algorithm are as shown in table 1.

TABLE 1: THE MAIN OPTIMIZATION PARAMETERS USED IN IAPSO

Parameter	Label	Setting
Inertia weight	w	0.4
Initial Self confidence	c_{11}	2
Initial Swarm confidence	c_{21}	2
Total number of iterations	i	1700

At first, IAPSO algorithm was implemented to optimize the objective function (11) without the use of the second term $C(\theta)$ which means that no constraint is applied on the peak SLL. The term $W(\theta)$ in the objective function (12) is described as follows

$$W(\theta) = \begin{cases} 50 & \text{if } \theta1 \leq \theta \leq \theta2 \text{ (wide null region)} \\ 1 & \text{otherwise} \end{cases} \quad (13)$$

This resulted in achieving a perfect wide null in the target sector and at the same time the main beam width is not changed. However, the peak SLL was increased which is not desirable. To allow the full control of the peak SLL to be less than or equal -30 db and to achieve a wide-band null at the exact placement simultaneously, the following term $C(\theta)$ is added to the cost function as in (12).

$$C(\theta) = \begin{cases} 5 & \text{if } MSL_1 \leq -30 \text{ or } MSL_2 \leq -50 \\ 0 & \text{otherwise} \end{cases} \quad (14)$$

However, as expected it is found that as the wide nulls become deeper, more broadening in the main beam width takes place. The maximum allowable tolerance in the main beam width broadening is controlled by the definition of band range of MSL_1 used in (14).

Figure 3 shows the radiation pattern of the classical Dolph-Chebyshev linear array.
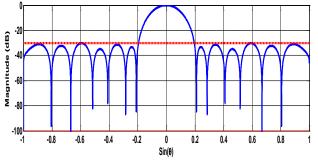

Fig. 3. Radiation pattern of a classical Dolph-Chebyshev linear array of 20 elements with SLL envelope at -30 db.

The values of the amplitude excitation coefficients of the Chebyshev radiation pattern shown are taken as the initial excitation coefficients value for the optimization process. The verification of the results of the simple PSO and the EPSO was done. The codes were successfully implemented to verify their results. The Simple PSO and the EPSO when applied to the linear 20 elements Chebyshev array resulted in wide null of -56 db and -67 db respectively. These results are shown in figures 4 and 5 respectively.
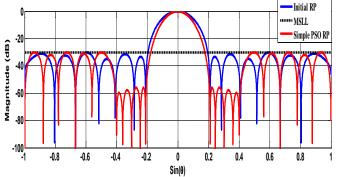

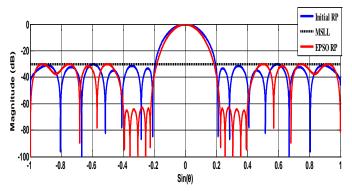Fig . 4 . Radiation pattern of an optimized Chebyshev linear array using simple PSO with null depth at -56 db.

Fig.5. Radiation pattern of an optimized Chebyshev linear array using EPSO with null depth at -67 db.

The IAPSO algorithm is applied to the initial amplitude excitation coefficients. The array pattern is optimized to show a perfect wide null depth at the desired band in between 0.3 and 0.5 which is the required band [10, 30] degrees. It was challenging in this optimization problem to keep the main beam width the same without change which extends from -0.2 to 0.2 which means its bandwidth equals approximately 23 degrees. Maximum allowable tolerance in the main beam broadening is controlled in the IAPSO. It was also important to get a full controllable MSLL at -30 db without any increase from this level. These requirements were successfully achieved as shown in figure 6.
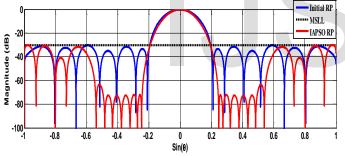

Fig.6. Perturbed (constrained optimized) -30 db Chebyshev pattern (N=20 elements) with main beam steered at 0˚ with symmetrical wide nulls imposed at θ=10˚ to 30˚ of -75 db.

The above figure shows maximum perfect wide nulls obtained in the required band at -75 db. It is observed from the figure that the main beam bandwidth is nearly the same and the MSLL of the optimized figure are preserved at the same level of -30 db. This proves that the IAPSO is able to achieve better results than the simple PSO and the EPSO.

4.2 Results Comparison

In this subsection, the results of the optimization using the IAPSO algorithm will be compared with the simple PSO and the EPSO algorithms. This comparison shows the superiority of the IAPSO over the other two algorithms. The radiation pattern result of the EPSO is shown in figure which shows that a wide null was achieved at -67 db.

The comparison between the algorithms (Simple PSO, EPSO and IAPSO) from the point of view of the convergence curves

is considered. Figures 7, 8 and 9 show the convergence curves of the Simple PSO, the EPSO and the IAPSO respectively.
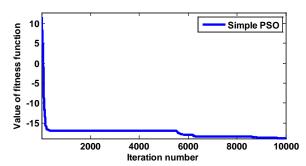

Fig.7. Convergence curve of the simple PSO scheme to achieve the target wide null at the determined band.
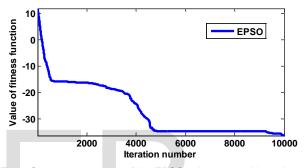

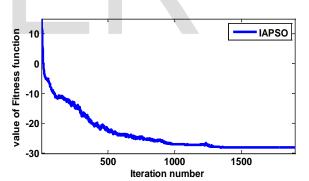Fig.8. Convergence curve of the EPSO scheme to achieve the target wide null at the determined band.

Fig.9. Convergence curve of the IAPSO scheme to achieve the target wide null at a certain desired band.
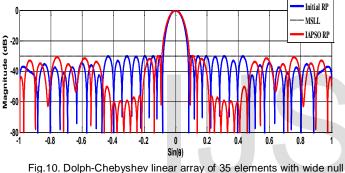
It is clearly shown that the IAPSO algorithm had greatly improved the optimization results. The number of iterations was clearly decreased to be 1700 iterations. The convergence was faster using the IAPSO than the simple PSO and the EPSO. Making fast convergence leads to decreasing the processing time a lot. The null depth was decreased in the desired band to -75 db along with preserving the main beam nearly the same having the same band width as well as the MSLL at the same level. As an overall, the IAPSO was able to achieve better results than both the EPSO and the simple PSO.

5. SENSITIVITY ANALYSIS OF THE PROPOSED IAPSO

In this section, the IAPSO scheme is applied on different case studies to show its efficiency and its ability to achieve nearly the same results if applied on different structures of arrays. Two case studies are also used to apply the IAPSO on a Chebyshev array with increased number of elements and on a different array antenna distribution with the same number of elements. The two case studies are shown below.
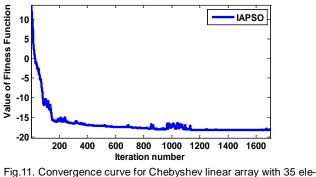
1) Increasing the number of elements of the array. This scheme was followed to show the effect of using the the simple PSO, EPSO and IAPSO algorithms on the same Chebyshev linear array but with increasing the number of elements to 35 elements.

The result of the proposed IAPSO algorithm is shown in figure 7. The figure shows that a perfect wide null depth achieved was -60 db in the required band [10°, 30°]. This proves that even using bigger arrays than the initially used shows the ability of the algorithm proposed to achieve good results.

Fig.10. Dolph-Chebyshev linear array of 35 elements with wide null depth achieved at -60 db at the band [10°, 30°] using IAPSO.

The convergence curve in figure 11 shows that by increasing the number of elements of the array to 35, convergence of the algorithm occurs with nearly the same speed as when using only 20 elements. This signifies that faster convergence occurs if compared to the EPSO and the simple PSO whose convergence curves for 35 elements of Chebyshev array are as well shown in figures 9 and 10 respectively.

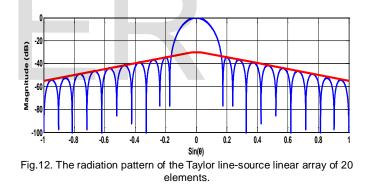Fig.11. Convergence curve for Chebyshev linear array with 35 elements using IAPSO.

2) Using a different array antenna distribution with the same number of elements.

The array distribution that was also used was the Taylor distribution. The Taylor linear array antenna of 20 elements was also designed. The Taylor produces a pattern whose inner minor lobes are maintained at a constant level and the remaining ones decrease monotonically. Taylor one parameter array results in a monotonically decreasing pattern [18]. For some applications, such as radar and low-noise systems, it is desirable to sacrifice some beam width and low inner minor lobes to have all the minor lobes decay as the angle increases on either side of the main beam. In radar applications this is preferable because interfering or spurious signals would be reduced further when they try to enter through the decaying minor lobes. The initial Taylor design of the elements was done using the following formulas to calculate the initial amplitude excitation coefficients

$$I_n(z) = \begin{cases} J_0\left[j\pi B\sqrt{1 - \left(\frac{2z}{l}\right)^2}\right] & -\frac{1}{2} \le z \le +\frac{1}{2} \\ 0 & \text{otherwise} \end{cases} \quad (15)$$

Where J_0 is the Bessel function of the first kind of order zero, l is the total length of the continuous source and B is a constant to be determined from the specified side lobe level. These initial amplitude coefficients are used to get the radiation pattern of the initial design of the Taylor linear array antenna which is shown in figure 12. Mathematical details of Taylor one parameter method for linear array are given in [10].

Fig.12. The radiation pattern of the Taylor line-source linear array of 20 elements.

The IAPSO scheme was then applied to the designed Taylor distribution linear array of 20 elements. The same objective was to get wide nulls at the specified position band of [23.5°, 30°].

The IAPSO could successfully achieve nearly the same success rate that it achieved in using the Dolph-Tchebyshev array which is shown in figure 13.
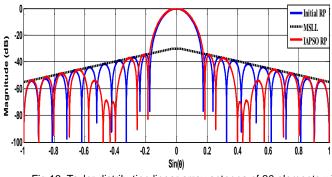
Fig.13. Taylor distribution linear array antenna of 20 elements with perfect wide nulls achieved at -72 db in the band [23.5˚, 30˚].

It is shown that the IAPSO was able to achieve wide nulls in the specified band with depth of -72 db. The convergence curve is also shown in figure 14. It is clear that the IAPSO is the fastest in convergence than both the simple PSO and the EPSO.
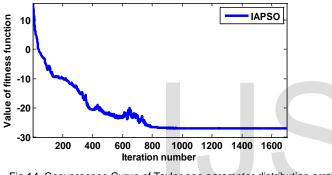

Fig.14. Convergence Curve of Taylor one parameter distribution array using IAPSO scheme.

The obtained results are compared all together in table 2 to show the robustness and the high efficiency of the IAPSO algorithm.

TABLE 2: COMPARISON OF THE RESULTS OBTAINED OF THE THREE ALGORITHMS USED FROM THE POINT OF VIEW OF THE MAXIMUM NUMBER OF ITERATIONS USED AND THE NULL DEPTH ACHIEVED.

Array types	Comparison points	SPSO	EPSO	IAPSO
Chebyshev 20 element	iteration	10000	10000	1700
	Null depth	-56 db	-67 db	-75 db
Chebyshev 35 elements	iteration	10000	10000	1700
	Null depth	-50 db	-55 db	-60 db
Taylor one parameter	iteration	10000	10000	1700
	Null depth	-52 db	-63 db	-72 db

This shows the robustness of the applied algorithm. It proves that the IAPSO can be successfully applied on different systems and can achieve wide nulls in the specified directions of interference with high performance and efficiency.

6. CONCLUSION

In this paper, a novel method has been proposed to solve the problem of null placement in linear array systems. The method used uses amplitude coefficients perturbations to achieve the objective desired of null placement. The computer simulation results shows that the IAPSO is capable of forming perfect wide nulls at any prescribed direction controlling the amplitude of each array element while keeping the pattern as close as possible to Chebyshev initial pattern. The algorithm had shown its robustness when used with different antenna systems with increased element's number and different array distribution like the Taylor one parameter array. The IAPSO can obtain the patterns with satisfactory null depth and maximum side lobe level. The algorithm had shown its fast convergence and its great ability to achieve the best optimum solution and being applicable in real world problems compared to other algorithms such as the SPSO and the EPSO.

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