Failure correction of linear antenna arrays with optimized element position using Grey Wolf Algorithm

N. Lakhlef, H. Oudira and C. Dumond

Abstract—**The paper concerns the problem of monitoring linear antenna arrays using grey wolf optimization method (GWO). When an abnormal event (fault) affects an array of antenna elements, the radiation pattern changes and significant deviation from the desired design pattern can occur. In this paper, reconfiguration of the amplitude and phase distribution of the remaining working elements in a failed array is considered. This latter can improve the side lobe levels (SLL) and also maintain the null position. The main purpose of using the GWO technique is its ease of implementation and a high performance computational technique. To assess the strength of this new scheme, several case studies involving different types of faults were performed. Simulation results clearly have shown the effectiveness of the proposed algorithm to monitor the failure correction of linear antenna arrays.**

Index Terms*—*failure correction;Linear Antenna Array;SLL; GWO.

I. INTRODUCTION

IN many applications such as satellite and radar communication systems, highly directive radiation patterns are needed which is generally generated by the use ofa set of multiple connected antennas, which is called antenna array, [1–5]. In this latter, it is possible to obtain a preferred radiation diagram with reduced side lobe level by controlling the current weights and excitations of individual radiating elements and also by optimizing the geometry of the array. Parameters estimation to yield a preferred radiation diagram is the main task in the synthesis of pattern array. In this domain different analytical and numerical methods have been evaluated and applied to face this issue [6].But, the situation becomes more difficult and complicated if one or more elements in the antenna array fail due to some unforeseen reasons. These faults occurrence in antenna array lead to changes in radiation diagram, which degrades the characteristics of the whole array in terms of increasing side lobe levels (SLL), and decreasing the gain and directivity of the antenna [7,8]. In the element failure compensation process, the weights and excitations of the remaining working elements are re-adjusted to form a new diagram that is similar as max as possible to the original. In the open literature, numerous numerical and soft-computing based techniques have been successfully applied to rectify the damages occur to the pattern array [9-13]. For instance, the application of genetic algorithm to reduce the SLL for the damaged array antenna is proposed in [10]. However, some aspects such as high performance computational time and the local minimum don't seem to be taken into consideration, which are very important issues to be addressed. For SLL reduction in failed array, Grewal, N and all [14] used the method of Fire fly; while Ramsdale and Howerton[15] discussed the element failure effects on the achievable side lobe level of a linear array. Sim and Er[16] deal with, in the occurrence of element failures, the issue of the SLL reduction for general arrays.

In this work the issue of monitoring linear antenna arrays using grey wolf optimization method (GWO) is considered. Weights amplitude and phase distribution of the lasting working elements in a faulty array are re-adjusted. This latter can improve the side lobe levels (SLL) and also keep the directivity in the preferred direction. The problem of the failure element position effect is also considered. The main point of using the GWO technique is its ease of implementation and a high performance computational method. To assess the strength of this new scheme, different types of failures, as case studies, were performed. Simulation results clearly have shown the usefulness of the proposed algorithm to correct the failure correction of linear antenna arrays. The results obtained are promising in terms of performance and efficiency.

The paper is outlined as follow: Section II introduces and overview of linear antenna array. Section III presents the problem formulation and optimization process. Then, description of the proposed technique (GWO) is given in section IV, while results of simulation and related discussions are evoked in section V. Finally, some conclusions from this work are reported in section VI.

N. Lakhlef is with the Electronic Department, University of Mouhamed Boudiaf, M'Sila, Algeria, and Electrical Engineering Laboratory (LGE) M'Sila, Algeria (e-mail: nora.lakhlef@ univ-msila.dz).

H. Oudira is with the Electronic Department, University of Mouhamed Boudiaf, M'Sila, Algeria, and Electrical Engineering Laboratory (LGE) M'Sila, Algeria (corresponding author e-mail: houcine.oudira@ univ-msila.dz).

C. Dumond is with PRISME Institut, IUT of Chartres, University of Orléans, France (e-mail: christophe.dumond@univ-orleans.fr).

II. LINEAR ANTENNA ARRAY OVERVIEW

For a linear array (Fig.1), we distinguish two types, an array where the number of elements is odd and an array where the number of elements is even. The symmetric odd linear array is an array where their elements are symmetrical two with two to an antenna placed at the origin (x = 0) and each pair or two symmetrical elements have the same amplitude and phase excitation as shown in Fig.2. In the symmetric even linear array, there is no antenna (element) is placed at origin as shown in Fig.3.

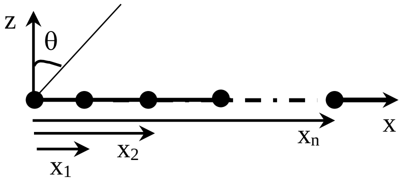

Fig.1. Linear antennas array

The array factor of a linear antenna is given by:

$$AF = \sum_{i=0}^{n} I_i e^{j(kx_i sin\theta + \beta_i)} \tag{1}$$

Where:
n: number of elements, I_i and β_i are current amplitude and phase respectively of the element of order i, k $(2\pi/\lambda)$, is the wave number and θ is the azimuth angle, x_i is the distance between the origin and element (i).

The array factor of an odd symmetric linear array (Fig.2) is given by:

$$AF = I_0 e^{j(\beta_0)} + 2\sum_{i=1}^{n} cos(kx_i sin\theta + \beta_i) \tag{2}$$

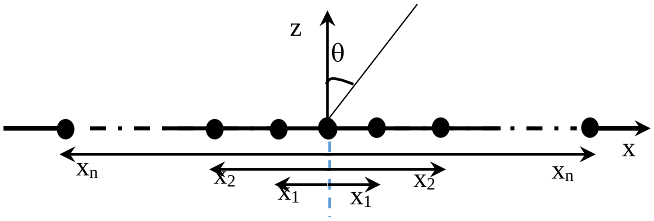

Fig.2. Odd symmetric linear antenna array

If we take, $\beta_0 = 0$, the Array factor of an odd antenna becomes :

$$AF = I_0 + 2\sum_{i=1}^{n} cos(kx_i sin\theta + \beta_i) \tag{3}$$

The array factor of an even symmetric linear array (Fig.2) is given by:

$$AF = 2\sum_{i=1}^{n} cos(kx_i sin\theta + \beta_i) \tag{4}$$

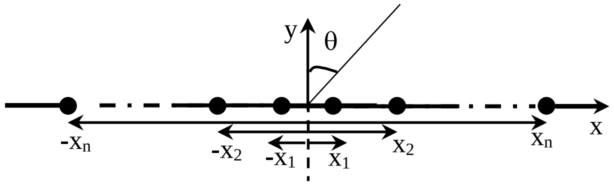

Fig.3. Even symmetric linear antenna array

III. PROBLEM FORMULATION

Let us consider that a 2n+1 element linear array. Assuming that the elements are in symmetrically excited configurations about the center of the array, placed along x axis as shown in Fig. 4. The Array Factor (AF) is expressed mathematically as [17]:

$$AF = w_0 + 2\sum_{i=1}^{n} w_i\, cos(kidcos\theta + \psi_i) \tag{4}$$

Where w_i, and ψ_i are the weight amplitude and phase excitation of ith element in the array. k$(2\pi/\lambda)$, is the wave number, θ is the azimuth angle and dis the distance between two consecutive elements(i-1) and (i).
To avoid the effect of grating lobs appearance and mutual coupling, the inter elements spacing d is fixed to 0.5 λ.
In this process of optimization, a design is done to reduce the side lobe level of the radiation pattern without affecting the directivity of the main lobe. To accomplish this goal, we considered the optimization of two vectors $w = [w_1, w_2, ..., w_n]$, and $\psi = [\psi_1, \psi_2, ..., \psi_n]$ which are weight amplitudes, and phases excitation respectively using GWO algorithm

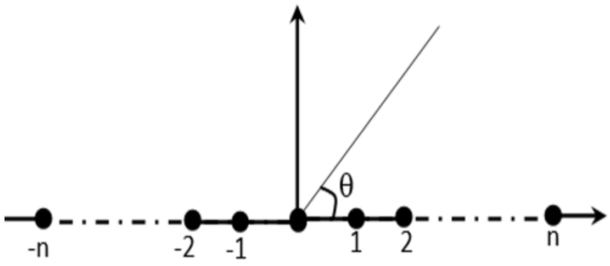

Fig.4. Structure of a linear antennas array

IV. GWO METHOD

We present in this section an off-line optimization technique for parameters finding of (4). To this effect, we consider a new kind of optimization method called “Grey Wolf Optimizer (GWO) algorithm” that is introduced in 2014 by Mirjalili[18]. The philosophy of this technique is inspired from searching and hunting process of grey wolves. In order to model mathematically the social hierarchy of wolves when designing GWO, the three main steps of hunting, searching for prey, encircling prey and attacking prey are implemented. Since this method does not make any assumptions about the problem, it can therefore be applied to a wide class of problems. Details of the Grey Wolf method are given in [18, 19]. The most suitable solution is called alpha (α), the second best is beta (β), and the third best is named delta (δ). The rest of the candidate solutions are all considered to be omegas (ω). All of the omegas should follow the dominant types of grey wolves during the searching and hunting.

The social behavior is mathematically modeled as follow:

$$\vec{D} = \left|\vec{C}.\vec{X_p}(t) - \vec{X}(t)\right| \tag{5}$$

$$\vec{X}(t+1) = \vec{X_p}(t) - \vec{A}.(\vec{D}) \tag{6}$$

Where t indicates the current iteration, D is the distance, $\vec{X_p}$ is the prey position vector, $\vec{X}$ indicates the grey wolf position vector, $\vec{A}$ and $\vec{C}$ are coefficient vectors and calculated using,

$$\vec{A} = 2\vec{a}.\vec{r_1} - \vec{a}$$

$$\vec{C} = 2.\vec{r_2}$$

Where components of $\vec{a}$ are linearly decreased from 2 to 0 over the course of iterations and$\vec{r_1}$, $\vec{r_2}$ are random numbers in [0,1]. The equations for position updating are shown as follows.

$$\begin{gathered} \vec{D_\alpha} = \left|\vec{C_1}.\vec{X_\alpha} - \vec{X}\right| \\ \vec{D_\beta} = \left|\vec{C_2}.\vec{X_\beta} - \vec{X}\right| \\ \vec{D_\delta} = \left|\vec{C_3}.\vec{X_\delta} - \vec{X}\right| \end{gathered} \tag{7}$$

$$\begin{gathered} \vec{X_1} = \vec{X_\alpha} - \vec{A_1}.(\vec{D_\alpha}) \\ \vec{X_2} = \vec{X_\beta} - \vec{A_2}.(\vec{D_\beta}) \\ \vec{X_3} = \vec{X_\delta} - \vec{A_3}.(\vec{D_\delta}) \end{gathered} \tag{8}$$

Where $\vec{X_1}, \vec{X_2}, and\ \vec{X_3}$ represent the best three solutions so far during the iteration process, each wolf in the group update its position accordingly.

$$\vec{X}(t+1) = \frac{\vec{X_1}+\vec{X_2}+\vec{X_3}}{3} \tag{9}$$

To solve the above optimization problem given by (4), each search agent (position) is considered as a vector of the parameters of optimal pattern synthesis. In the process of compensation for the element failure, the excitations of the working elements are re-adjusted to form a new pattern that is close to the original. In the sense that, the corrected radiation pattern Fc(θ) should be as close as possible to the original diagram Fo(θ). The fitness function to be minimized by the proposed algorithm is given as follow.

$$Fitness\ function = \sum_{\theta}(F_C(\theta) - F_O(\theta))^2 \tag{10}$$

The pseudo code of the Grey Wolf optimization algorithm is found in [18]. The GWO has the ability to search for total optimal results without fixing any parameters as classical methods.

A flowchart describing the operation of the proposed method is shown in Fig.5. The algorithm begins by introducing the population size and maximum number of iterations. After that an initial random positions is generated by using the Matlab function "rand". To deal with the randomness of the algorithm, specific ranges limitation for the parameters finding such as the weights amplitude and phase's excitation are considered.

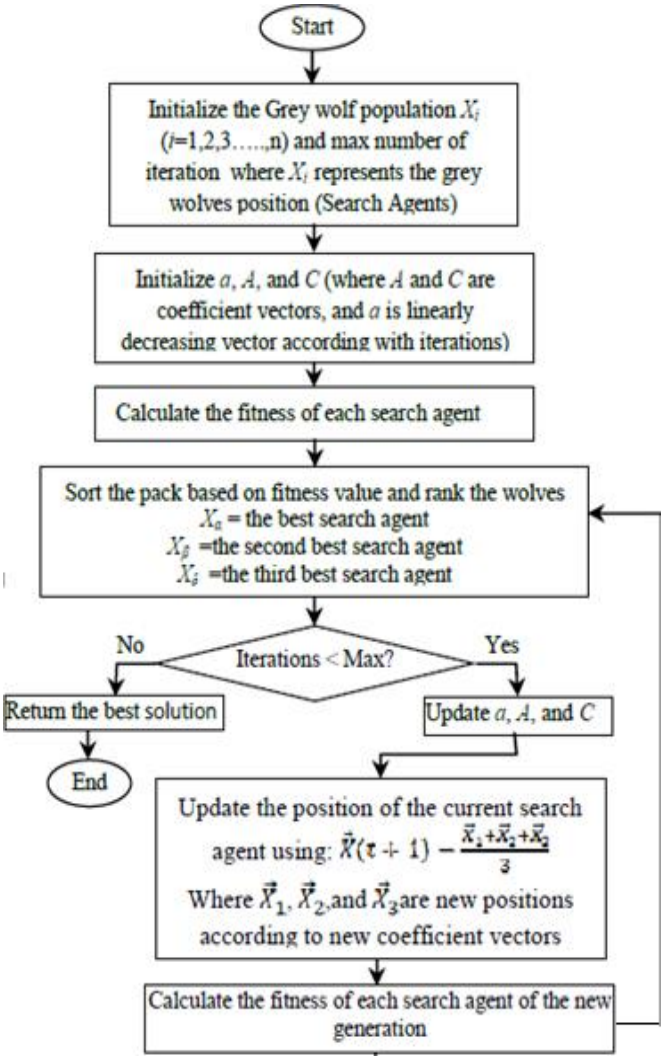

Fig. 5. Flowchart of the GWO algorithm.

The fitness function for each individual position is evaluated. Then it is classified to draw alpha, beta and delta members of the GWO method. Accordingly, other individuals update their positions. At the end of this phase, just the best positions of current iteration will be taken into consideration for determining the alpha, beta and delta members, and the procedure of updating the search agents' positions according to their positions is repeated. The same process is done until the maximum number of iterations is reached [15-17].

V. RESULTS AND DISCUSSION

We consider a linear array composed of 15 elements placed symmetrically as regard to the origin. If the element at position (-6) in the array becomes failed, the array factor for this active antenna array can be given by the following expression as follows:

$$\mathrm{AF} = \sum_{\substack{i=-n \\ i\neq -6}}^{n} w_i \exp(j(kid\cos\theta + \psi_i)) \quad (11)$$

The original pattern in this case is obtained through the optimization of the weight amplitude and phase excitation of all sensors, while keeping uniform spacing equal to 0.5 λ, that involve maintaining the gain of the main beam at a particular direction while simultaneously suppressing the side lobe level. The desired diagram chosen in this case is a Gaussian function which is given by:

$$\mathrm{Fd} = n.\exp^{\frac{-\theta^2}{\sigma}} \quad (12)$$

Where: n is the number of radiating elements, it can be considered as the theoretical maximum of the gain, θ is the position angle, σis the standard deviation.

A. *Effects of weights amplitude*

When the element at position (-6) is supposed damaged in the active antenna array. The array diagram of the failure array is done by setting the amplitude weight of damaged element to zero in the amplitude weights of the initial pattern. In this case, it has been assumed that the excitation phase of all elements is zero which leads to a one degree of freedom which is the amplitude excitation

TABLE 1
. COMPARISON RESULTS FOR ORIGINAL AND RECOVERED WEIGHTS

Position of Sensor	Original weights	Recovered weights
-7	*0.100*	*0.1001*
-6	*0.1960*	*0.0000*
-5	*0.2920*	*0.1398*
-4	*0.4102*	*0.2999*
-3	*0.5148*	*0.3935*
-2	*0.6078*	*0.5425*
-1	*0.6635*	*0.6576*
0	*0.6870*	*0.7666*
1	*0.6635*	*0.8044*
2	*0.6078*	*0.8024*
3	*0.5148*	*0.7257*
4	*0.4102*	*0.6111*
5	*0.2920*	*0.4455*
6	*0.1960*	*0.2992*
7	*0.1000*	*0.1345*
SLL(dB)	*-30.4251*	*-29.5963*

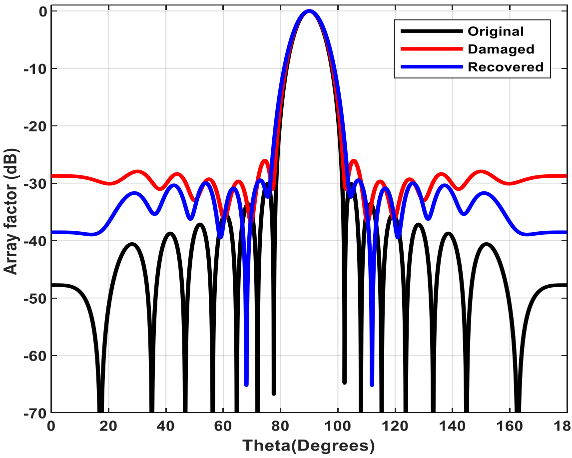

Fig. 6. Original, Damaged and Compensated pattern with failed element position at (-6) in 15 element antenna array

From Fig.6, it is clearly noticed that due to the element failure, the radiation diagram perturbs in terms of side lobes level (SLL= -26.1430). Therefore the GWO is used to find the optimum amplitude weights of the remaining working elements, in the sense of forming a new pattern that is close as possible to the original. The values of the amplitude weights of the original and recovered array are tabulated in table 1.

After the GWO method is applied, the SLL was reduced to -29.5963dB. Thus, the proposed scheme can be reached a -3.42 dB SLL reduction and two nulls are restored.

B. *Effects of excitation phase*

The same consideration as the first case is considered where the element at position (-6) is supposed damaged in the active antenna array. The array diagram is done by setting the amplitude and the phase excitation of damaged element to zero. In this case, it has been assumed that the weight amplitude of all elements is fixed which leads to a one degree of freedom which is the phase excitation.

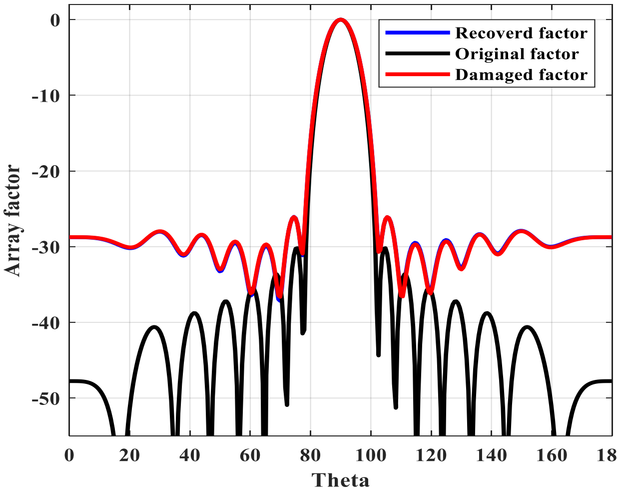

Fig. 7. Original, Damaged and Compensated pattern with failed element position at (-6) in 15 element antenna array

TABLE 2
COMPARISON RESULTS FOR ORIGINAL AND RECOVERED WEIGHTS

Position of Sensor	Original weights	Recovered phase excitation
-7	*0.100*	*3.1957*
-6	*0*	*0*
-5	*0.2920*	*1516*
-4	*0.4102*	*3.1536*
-3	*0.5148*	*3.1532*
-2	*0.6078*	*3.1545*
-1	*0.6635*	*3.1538*
0	*0.6870*	*3.1543*
1	*0.6635*	*3.1536*
2	*0.6078*	*3.1541*
3	*0.5148*	*3.1550*
4	*0.4102*	*3.1539*
5	*0.2920*	*3.1494*
6	*0.1960*	*3.1490*
7	*0.1000*	*3.1449*
SLL(dB)	*-30.4251*	*-25.5963*

From the table 2 and figure 7, it is noticed that the phase excitation has no effect in correcting the array failure issue.

C. *Effects of excitation amplitude and phase*

In this study the optimization process is used, in the same condition to find the optimum weights amplitudes and phases excitation of the lasting working sensors, to recompense for the element failure in the array. In this case only the space of inter-element is kept fixed and equal to 0.5 λ

Figure 8 illustrates the initial radiation pattern of the 15 element linear array design with main beam and an SLL of -30.4251dB. When the element position (-6) of the array become damaged, the side lobe level increases to the value of -26.1430dB. The GWO has been applied to correct the failed diagram according to the objective function expressed by equation (10). The obtained results (SLL=-28.2150dB) show the efficiency of the proposed algorithm in solving the array failure issue.

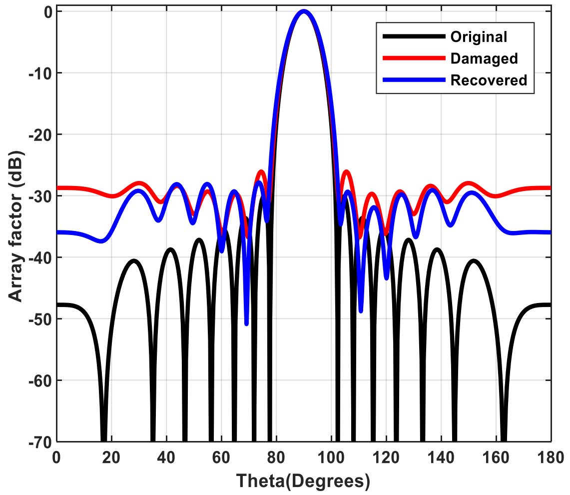

Fig.8 . Original, Damaged and Compensated pattern with failed element position (-6) in 15 element antenna array.

From figure 7 and 8, it can be noticed that weights amplitude has more influence in correcting the array failure issue than the amplitude and phase excitation together.

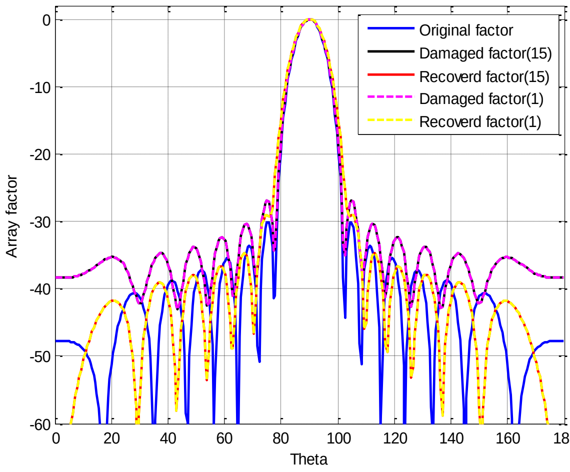

Fig.9 . Original, Damaged and Compensated pattern with failed element position (-7 and 7) in 15 element antenna array.

To remedy the problem of failure caused by certain elements for a linear antenna array, the positions of the defective elements must be taken into account. So we distinguish two cases, the first one is the defective elements are symmetrical, in which each defective element has its symmetry defective one and the other case is the opposite case as it is studied in the previous section. For this reason; in this study the first case is taken into consideration where the elements in the positions 15, 1, 13 and 3 are considered as failed. Figure 9, and 10 show the original, damaged (w15 and w1), damaged (w13 and w3), and recovered radiation patterns respectively. From these figures, it can be noticed that the proposed algorithm can deal with the problem of failure correction with efficiency and the side lobe level is influenced by the element failure position. To confirm this later remark, figure 8 shows the effect or the influence of element failure position on the side lobe level.

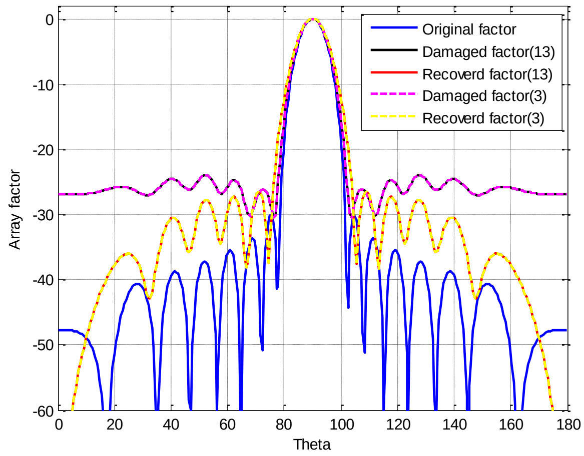

Fig.10 . Original, Damaged and Compensated pattern with failed element position (-5 and 5) in 15 element antenna array.

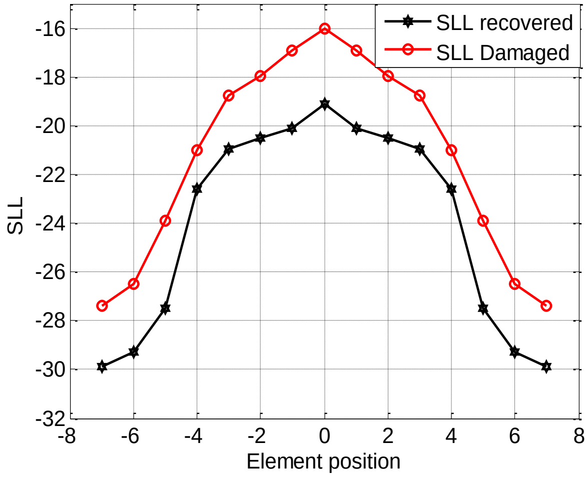

Fig. 11: Comparison of the Side lobes level as a function of the damaged element position.

Figure 11 and table 3 show that the radiation pattern deformation increases when the damaged element is close to the middle of the antenna, the maximum deformation is in this case where the defective element ranks 0.

TABLE 3
COMPARISON RESULTS FOR DAMAGED AND RECOVERED SLL VALUES

Element position	SSL (damaged)	SSL (recovered)
-7	27.3716	29.9016
-6	26.4848	29.3047
-5	23.8801	27.4660
-4	21.0089	22.6054
-3	18.773	20.9786
-2	17.9809	20.4961
-1	16.9194	20.0984
0	16.0331	19.0984
1	16.9194	20.0984
2	17.9809	20.4961
3	18.7730	20.9786
4	21.0089	22.6054
5	23.8801	27.4660
6	26.4848	29.3047
7	27.3716	29.9016

D. Comparison with literature

We compared in this section the obtained results with those of the reference [20-22]. For the seek of an objective comparison, we study the same cases which are presented in the cited reference.

Case 1: weights amplitude has been optimized keeping excitation phase and space of inter-element fixed. In this case, as an example of comparison, a Classical Dolph-Chebyshev linear array of 21 elements with inter-element spacing of λ/2 is used as the original pattern [20]. We suppose that the elements w_{-6} and w_{-9} are failed; GWO is used to suppress the SLL by re-adjusting the weights of lasting active sensors(figure 12).The side lobes of the examination array is taken as -30dB and Table 4 depicts the weights amplitude for the Chebyshev, faulty and recovered pattern in the this case.

Case 2: weights amplitude and phase excitations have been optimized keeping the space of inter-element fixed. The same conditions as the first case are taken in consideration. Figure 13 shows the array factor of Chebyshev, faulty and recovered diagram by the use of the proposed method, reference [21], and reference [22]. It is clearly seen that the results obtained by the proposed method surpass those obtained by [21-22] in terms of reducing the SLL level. Table 5 confirms this remark by reporting the considered SLL values.

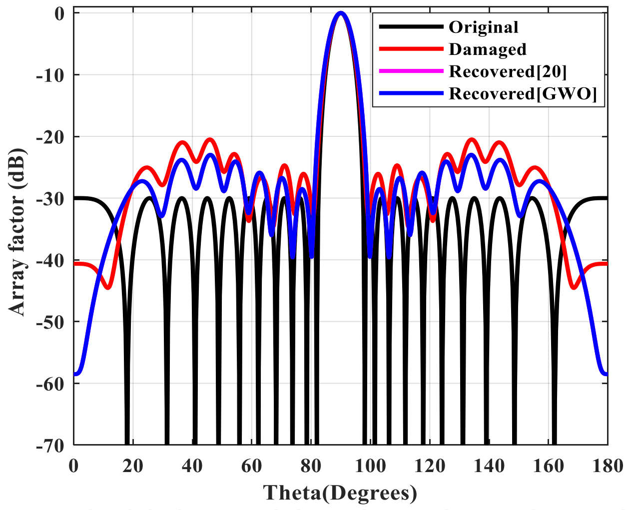

Fig. 12 .The Chebyshev original, damaged (w-9 and w-6), and recovered radiation patterns.

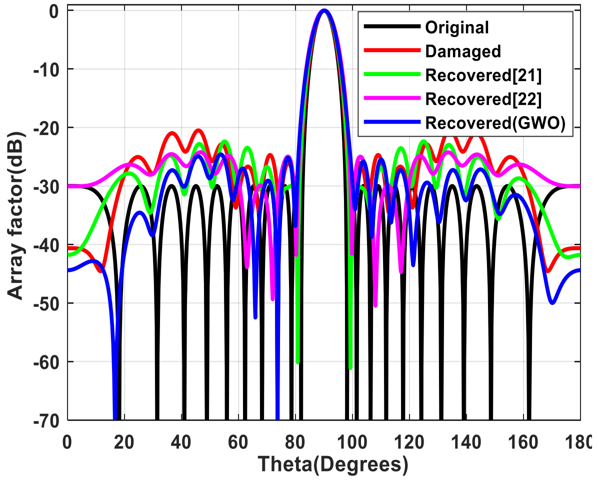

Fig.13. The Chebyshev original, damaged (w-6 and w-9), and recovered radiation patterns.

TABLE 4
WEIGHTS AMPLITUDE OF CHEBYSHEV, FAULTY AND RECOVERED PATTERN.

Chebyshevweights N=21	Damaged weights	Recovered weights (GWO)	Recovered weights [21]
0.3337	*0.3337*	*0.1001*	*0.1315*
0.2789	*0*	*0*	*0*
0.3780	*0.3780*	*0.1006*	*0.2908*
0.4849	*0.4849*	*0.1048*	*0.4026*
0.5946	*0*	*0*	*0*
0.7014	*0.7014*	*0.1843*	*0.5226*
0.7995	*0.7995*	*0.2684*	*0.6438*
0.8829	*0.8829*	*0.3383*	*0.7581*
0.9465	*0.9465*	*0.4226*	*0.8575*
0.9864	*0.9864*	*0.5098*	*0.9345*
1.0000	*1.0000*	*0.5817*	*0.9833*
0.9864	*0.9864*	*0.6346*	*1.0000*
0.9465	*0.9465*	*0.6669*	*0.9833*
0.8829	*0.8829*	*0.6755*	*0.9345*
0.7995	*0.7995*	*0.6478*	*0.8575*
0.7014	*0.7014*	*0.5960*	*0.7581*
0.5946	*0.5946*	*0.5120*	*0.6438*
0.4849	*0.4849*	*0.4316*	*0.5226*
0.3780	*0.3780*	*0.3185*	*0.4026*
0.2789	*0.2789*	*0.2316*	*0.2908*
0.3337	*0.3337*	*0.1387*	*0.3152*
SLL= -30dB	*SLL=-20.3529dB*	*SLL=-27.1411dB*	*SLL=-23.0528 dB*

TABLE 5
COMPARISON STUDY FOR ORIGINAL, DAMAGED AND RECOVERED ARRAY.

Array Factor	Side Lobes Level (dB)
Original	-30
Damaged	-20.3529
Recovered (Proposed MGWO)	-25.0659
Recovered [21]	-22.4104
Recovered [22]	-25.0659

Another study taken into consideration in this work is the failure pattern correction with the use of minimum number of elements that has a desired pattern as close as possible to Chebyshev pattern. The optimization process in this case is based on the use of GWO technique to correct the failure diagram with the use of minimum number of elements. In this scenario, we assumed that two sensors (w-6 and w-9) are damaged in an array of 21 sensors. The power diagram for this damaged array using minimum number of sensors can be given by the following expression as follows:

$$AF = \sum_{\substack{i=-n \\ i\neq p}}^{n} w_i \exp(j(kid\cos\theta + \psi_i)) + \sum_{\substack{i=-n \\ i\neq q}}^{n} w_{iChe} \exp(j(kid\cos\theta + \psi_i)) \qquad (13)$$

Where:
p:is the position of the damaged sensors and sensors that are not used in the correction of the damaged array.
q: is the position of sensors that are used in the correction of the damaged array.
w_{iChe}:is the weights of Chebyshev pattern

From fig. 14 it is clear that we obtain almost the same recovered pattern from the minimum number of sensors (10 sensors) by the proposed technique positioned at (-10, -8, -6, -5, -4, -3, -2, -1, 0, 10) compared to use of 19 sensors as in the previous case. These results are confirmed in the table 6 by the reported values of the two cases. Also, it can be noticed from this table that, the results obtained by minimum number of sensors in the case of the optimization of amplitudes excitation only are competitive to those obtained by [22] and by full number of sensors in the case of reconfiguration of both amplitude and phase excitation.

TABLE 6
COMPARISON ANALYSIS FOR RECOVERED WEIGHTS.

Position of Sensor	Recovered weights (9 sensors)	Recovered weights (19 sensors)	Recovered weights [22]
-10	0.1002	-0.0416 + 0.0909i	0.0798+0.0014i
-9	0	0.0000 + 0.0000i	0
-8	0.1771	-0.1158 + 0.0349i	0.1160-0.0005i
-7	0.2183	-0.1153 + 0.0579i	0.3809 -0.0003i
-6	0	0.0000 + 0.0000i	0
-5	0.3509	-0.1910 + 0.0768i	0.5845+0.0003i
-4	0.4798	-0.2758 + 0.1053i	0.7214 - 0.0007i
-3	0.5516	-0.3221 + 0.1305i	0.8643 + 0.0007i
-2	0.6059	-0.3862 + 0.1532i	0.9775 - 0.0008i
-1	0.7239	-0.4407 + 0.1765i	0.9765 + 0.0006i
0	1.0000	-0.4903 + 0.1938i	0.9498 + 0.0000i
1	0.9864	-0.5210 + 0.2098i	0.9765 - 0.0006i
2	0.9465	-0.5412 + 0.2155i	0.9775 + 0.0008i
3	0.8829	-0.5409 + 0.2173i	0.8643 - 0.0007i
4	0.7995	-0.5192 + 0.2059i	0.6545 - 0.0004i
5	0.7014	-0.4884 + 0.1938i	0.6545 - 0.0004i
6	0.5946	-0.4266 + 0.1694i	0.6545 - 0.0004i
7	0.4849	-0.3637 + 0.1472i	0.5845 - 0.0003i
8	0.3780	-0.2822+0.1121i	0.3809 + 0.0003i
9	0.2789	-0.2265+0.0925i	0.1160 + 0.0005i
10	0.2124	-0.1482+0.0592i	0.0798-0.0014i
SLL(dB	-25.0019	-25.0659	-25.0659

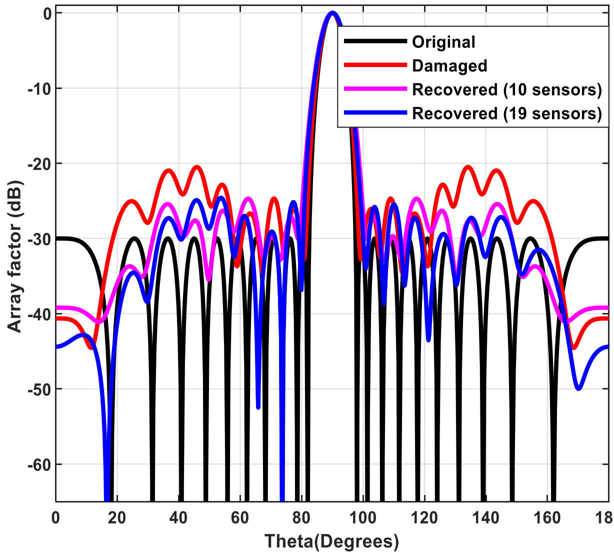

Fig. 14. The Chebyshev original, damaged (w-6 and w-9), and recovered radiation patterns.

VI. CONCLUSION

The problem of maintaining the directivity of the main beam and SLL suppression in failed antenna array is considered as an optimization problem and solved successfully using GWO. The task of the proposed method was to find the optimized set of the amplitude and phase excitations of the working elements in array to get the desired pattern. In this process of compensation, the SLL was reduced and main lob level restored at its original position. The proposed technique is simple and easy to implement and can be extended for arrays with complex study and geometry by modifying the associated evaluation function. The numerical simulation results showed that a better recovered pattern can be reached with the proposed GWO scheme.

The developed methodology can be helpful in increasing the life span of the arrays, particularly for the arrays without direct human access.

REFERENCES

[1] A. Basti, I. M Qureshi, W. Khan, I. Ulhaq, and S. U. Khan "Hybridization of Cognitive Radar and Phased Array Radar Having Low Probability of Intercept Transmit Beam forming". International Journal of Antennas and Propagation, vol. 2014, 11 pages, Islamabad- Pakistan, 2014.

[2] A. Basti, I. M Qureshi, W. Khan, and S.U Khan "Cognitive Frequency Offset Calculation for Frequency Diverse Array Radar", IEEE IBCAST2015, pp.641–645, 2015.

[3] B. Shoaib, I. M. Qureshi, S.U. Khan, I. Shafqat, U.I. Haq, "Adaptivestep-size modified fractional least mean square algorithm for chaotic time series prediction". Chinese Physics B, vol. 23, no. 5, 2014.

[4] S. Caorsi, M. Donelli, F. De Natale, A. Lommi, A. Massa,"Planarantennaarray control with genetic algorithms and adaptive array theory," IEEE Trans .Antenna Propagat, vol.52, no. 11, pp. 2919–2924, 2004.

[5] N. Lakhlef, H. Oudira, C. Dumond "Optimal Pattern Synthesis of Linear Antenna Arrays Using Modified Grey Wolf Optimization Algorithm" Instrumentation MesureMétrologie, Vol. 19, no. 4, pp. 255-261, August, 2020

[6] C.A Balanis, ''Antenna Theory and Design'', John Wiley and Sons, Inc., 2005.

[7] D. Vakula, N.Sarma, ''Fault diagnosis of planar antenna arrays using neural networks'', Prog. Electromagnetics Res. M 6, pp. 35–46, 2009.

[8] F. Harrou, M. ''Nounou, Monitoring linear antenna arrays using an exponentially weighted moving average-based fault detection scheme'', Syst. Sci. Control Eng. Open Access Journal, vol. 2, no. 1, pp.433–443, 2014.

[9] F. Harrou, and Y. Sun "Statistical monitoring of linear antenna arrays" Engineering Science and Technology, an International Journal, Vol.19, pp.1781–1787, 2016

[10] J.A. Rodriguez, F. Ares, E. Moreno and G. Franceschetti, "Genetic algorithm procedure for linear array failure correction," Electronics Letters, vol. 36, no. 3, Feb. 2000.

[11] K. Guney and S. Basbug, "Interference suppression of linear antenna arrays by amplitude-only control using a bacterial foraging algorithm," Progress In Electromagnetics Research, Vol. 79, pp.475–497, 2008.

[12] K. Guney and M. Onay, "Amplitude-only pattern nulling of linear antenna arrays with the use of bees algorithm," Progress In Electromagnetics Research, Vol. 70, pp. 21–36, 2007.

[13] N. Lakhlef, H. Oudira, C. Dumond "Failure Correction of linear Antenna Array using Grey Wolf Optimization" IEEE OMCS 2020, pp.384–388, Agadir, Morocco 2020.

[14] N. S Grewal, M. Rattan, and M. S. Patterh, "A linear antenna array failure correction using firefly algorithm," Progress In Electromagnetics Research M, Vol. 27, pp.241–254, 2012.

[15] D. J. Ramsdale, and R. A. Howerton, "Effect of element failure and random errors in amplitude and phase on the side lobe level attainable with a linear array,"J. Acoust, Soc. Am, Vol.68, no.1, pp.901–906, 1980.

[16] S. L. Sim, and M. H. Er, "Side lobe suppression for general arrays in presence of element failures," Electronics Letters, Vol. 33, no. 15, pp.1278–1280, 1997.

[17] F. Zhang, W. Jia, M. Yao. "Linear a periodic array synthesis using differential evolution algorithm". IEEE AntennWirelPropagLett; Vol. 12, pp.797–800, 2013.

[18] S. Mirjalili, S.M. Mirjalili, and A. Lewis, A, "Grey Wolf Optimizer," Advances in Engineering Software. Vol. 69, pp. 46-61, 2014.

[19] H. Oudira, A. Gouri, A. Mezache, ''Optimization of Disrtibuted CFAR Detection using Grey Wolf Algorithm'', Procedia Computer Science, Vol. 158, pp. 74-83, 2019.

[20] S. U. Khan, I. M. Qureshi, Z. Fawad, and A. Naveed ''Null Placement And Sidelone Suppression In Failed Array Using Symmertrical Element Failure Technique and Hybrid Heuristic Computation'', Progress In Electromagnetics Research B, Vol. 52, pp.165–184, 2013

[21] Yeo BK, Lu YL, Array Failure Correction With A Genetic Algorithm. IEEE Trans Antennas Propag, vol. 47, no. 5, pp.823-828, 1999.

[22] S. U. Khan, M. K. A. Rahim, A. Liaqat, "Correction Of Array Failure Using Grey Wolf Optimizer Hybridized With An Interior Point Algorithm", Front Inform Technol Electron Eng, Vol.19, no. 9, pp.1191-1202, 2018

N.Lakhlef received the Engineering degree and Magister degrees in Electronics from Ferhat Abbas University, Sétif, Algeria, in1991 and 1999, respectively.She joined the Electronics Department, University Mohamed el bachir el ibrahimi, el anceurbordjbouarreridj,in 2000 as a full-time Professor. She is a member of the LGE (Laboratoire de GénieElectrique) Laboratory, University Mohamed Boudiaf of M'sila, Her research interests include communication systems.

H. Oudira was born in Constantine, Algeria, on November 05,1980. He received the Engineering degree in Electronics/Communication, Magister degree and the Doctorate degree in semiconductor sensor in biomedicine from the University of Constantine, Algeria, in 2003, 2005 and 2009 respectively. He joined the Electronics Department, University Mohamed Boudiaf of M'sila, in 2009 as a full-time Professor. He is a member of the LGE (Laboratoire de GénieElectrique) Laboratory, University Mohamed Boudiaf of M'sila, Currently his main research interests include communication system, signal processing and renewable energy.

Christophe Dumond was born in Tulle, France, on October 22, 1966. He received the PhD in Optic Communications and Microwaves from University of Limoges, France in 1994. His works concern the electromagnetic answer of wire structures to fast transient perturbations. In 2007 he joined the Institut Pluridisciplinaire de Recherche en Ingénierie des Systèmes Mécaniques et Energétique (PRISME) of University of Orléans, France. His fields of research include fractal antennas, high Tc superconducting microstrip patch, phased arrays and implantable antennas for bio-telemetry. He is also a teacher and head of the electrical engineering department at the Institut Universitaire de Technologie (IUT) of Chartres, France.