Paper

Failure Correction of a Linear Array of Coupled Parallel Vertical Dipole Antennas

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https://doi.org/10.26636/jtit.2020.136419

Abstract—In this paper, a cuckoo search algorithm based on the combined characteristics of the brood parasite behavior and Levy flights is applied to correct the radiation pattern of a linear antenna array composed of parallel dipoles with faulty elements. An effort is made to restore the radiation pattern similar to one without any faulty elements, and the difference in the values of side lobe level and wide null depth of both patterns, as well as the voltage standing wave ratio obtained from the new voltage excitations become diminished. The examples presented in this paper show the effectiveness of this algorithm in correcting the radiation pattern of a linear array of 36 and 120 dipole antennas with four and ten failed elements, respectively. The results show that the matching condition and the wide null control produced by Cuckoo Search algorithm are more efficient in comparison with the benchmark failure correction algorithm. The approach adopted herein may be applied to other array configurations as well.

Keywords—array failure correction, cuckoo search algorithm, wide null depth, mutual coupling.

1. Introduction

Besides high gain, many other advantages, such as reception diversity, maximum signal-to-interference ratio over individual antennas, are offered in numerous applications with antenna arrays [1]. In spite of such advantages, the quality of individual applications is affected by undesired, elevated value of side lobe level (SLL), as well as by single and wide null depth (WND) [1]. This is visible in the radiation patterns whose appearance deteriorates even with a single faulty element in the array.

The servicing of faulty elements is time and cost-intensive. The idea of replacing failed elements is substituted by modifying beam weights [2]–[9], i.e. amplitudes and/or phase excitations of the remaining non-failed elements to the extent that the corrected radiation pattern looks the same as the original (non-failed) pattern. For example, Peters [2] utilized a conjugate gradient-based algorithm for the synthesis/failure correction of sum-and-difference patterns, and this work resulted in a partial compensation of performance degradation of arrays caused by element failures. Yeo and Lu utilized, in [3], a Genetic Algorithm (GA) for failure correction and concluded that the success rate depends on the initial weight of elements and on the number of failures. Rodriguez [4] proved that amplitude excitation of merely a few elements needs to be modified in order to correct the damaged radiation pattern, depending on the required SLL. Keizer [5] used the Inverse fast Fourier transform (IFFT) relationship between the array factor and current excitations and obtained current excitations in an iterative manner for the corrected pattern of ultra-low side lobes.

Yeo and Lu [6] illustrated a faster correction of the radiation pattern using the Particle Swarm Optimization (PSO) algorithm. Article [7]–[8] mentions that performance of isotropic linear antenna arrays may be improved by using multiple single and wide-null employments. In this paper, correction of the antenna array performance was achieved by minimizing SLL with null steering, without considering the mutual coupling effect. For a linear antenna array, the shaped beam patterns and the failure corrections are described in [9]. Also, the synthesis of flattop and cosecant squared beam patterns, along with failure correction, is discussed to decrease SLL, as well as to deviate ripple in the shaped beam region.

In a few specific applications, it is desirable to discard radiations at identified directions or to enforce the nulls in the same pattern. These types of approaches are very common in many communication systems and are deployed to enhance the signal-to-noise ratio by reducing unwanted interference. Literature reviews show that several techniques are adopted for beamforming, allowing null placements in any directions.

While considering the radiation pattern, in addition to the SLL, null placement [10]–[14] with a larger bandwidth has to be taken into consideration, as it is one of the advantages of antenna arrays in many applications. In paper [10], various approaches to null control are discussed. Again, literature review findings on null steering prove that algorithms such as GA are utilized for adaptive null steering and complex weights of the digital beam forming array are directly coded as algorithm chromosomes [11]. Guney and Akdagli illustrated, in their work [12], the usage of Tabu search for controlling amplitude only, and combined amplitude-phase, in order to produce single and multiple nulls in a linear antenna array. The authors in [13] generated a flat-top beam using linear isotropic antenna elements by adopting the Quantum Particle Swarm Optimization (QPSO) algorithm. Furthermore, this paper considered multiple null steering with least deviation in the ripple of the flat-top beam. These beams are effectively produced by changing excitation current amplitudes with phases either at 0° or at 180° of each element. In another paper [14], the QPSO algorithm is again used for the design of uniformly separated scanned linear antenna arrays of isotropic antennas with definite SLL values. In most of the techniques, null steering may be achieved by controlling complex weights, the amplitude-only, the phase-only and the position-only of the antenna array. This helps orient the main lobe in any desired direction and facilitates placing the nulls along the way of undesired sources.

A need arises to mention mutual coupling [1], [15]–[17] in practical antenna arrays, as it plays a crucial role in degrading the radiation pattern. The antenna – feed line matching characteristics need to be taken into consideration as well. In papers [15]–[16], an analysis of MC between a finite phased dipole array and its feed network is presented. The design of a phase-only reconfigurable antenna array including the MC effect is properly explained in [17]. Since intense research in the area of mutual coupling effects in antenna arrays is conducted worldwide, this paper rightly chose the inclusion of the same. When dealing with evolutionary algorithms, based on the initial success provided by them, new algorithms are coming into existence on a very rapid basis and these algorithms act as a great boon for many of the very complex optimization problems. A few algorithms, with GA [3]–[4] being one of their primitive representatives, enjoyed their superiority over the past few decades by generating solutions using their own inheritance, cross over, selection and mutation policies. PSO [6] – a stochastic computation method – impacted many optimization problems by using a particle's (solution's) position and velocity based on mathematical formulae. Advancements, in the two above-mentioned algorithms, have resulted in their modified versions, offering better solutions by fine-tuning the methods deployed. In this paper, the Cuckoo Search (CS) algorithm [7], [18]–[20], one of the recently introduced algorithms which has proven to be successful in solving many optimization problems, is used.

The contribution of this paper is to simultaneously consider the placement of wide null in the radiation pattern of a linear array of mutually coupled dipole antennas with more than one antenna failure, along with the reduction of SLL and voltage standing wave ratio (VSWR) using the CS algorithm. Another contribution of this paper is that the performance of the algorithms is studied for different numbers of dipole antenna elements as well. In addition, performance of the CS algorithm is compared with that of the PSO algorithm, validating the same parameters.

2. Methodology

A linear array of parallel vertical dipole antennas placed along the x axis is shown in Fig. 1.

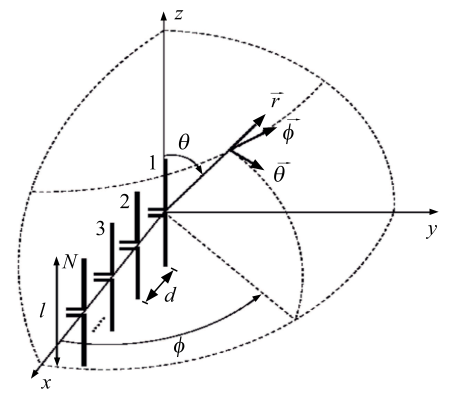

Fig. 1. Geometry of a linear array of parallel vertical dipole antennas with elements placed along the x axis.

The far field pattern [1] F_F for a linear array of N number of symmetrical parallel vertical dipole antennas in u-domain and in the x-y plane (horizontal) is given by:

$$F\_F(u) = 2\sum_{n=1}^{N} C_n \cos\left[(n-0.5)kdtu\right] e^{j\varphi_n}\, Element\ pattern(u)\,, \tag{1}$$

where

$$Element\ pattern(u) = \frac{\cos(0.5\,\pi u)}{\sqrt{1-u^2}}\,.$$

In Eq. (1), C refers to the current excitations (amplitudes), k being the wave number and d being the inter element spacing = 0.48 times the wavelength [21] and $u = \cos\phi$ with ϕ being the azimuthal angle. The normalized power pattern is equal to 20 times the logarithm of the far field pattern maximum value. The current amplitudes are obtained by dividing the voltage excitations by mutual impedance matrix [1], [15]:

$$V = C_p Z_{pp} + \sum_{q\neq p} C_q Z_{qp}\ , \tag{2}$$

where Z_{pp} refers to self-impedance and Z_{qp} refers to mutual impedance between p and q dipoles. The active impedance [15] of the dipole p is:

$$Z_p^A = \frac{V_p}{C_p} \,. \tag{3}$$

The VSWR parameter signifies the importance of matching characteristics of the antenna with the feed lines. A 1:1 ratio of VSWR implies that the antenna is matched with the feed line. In practice, a VSWR = 2 is suitable for most applications. The maximum value of VSWR is given by:

$$VSWR_{\max} = \frac{1+|\Gamma|_{\max}}{1-|\Gamma|_{\max}} \,, \tag{4}$$

where Γ is the reflection coefficient across the p-th dipole and is equal to $\frac{Z_p^A - Z_0}{Z_p^A + z_0}$, and Z_0 refers to the characteristic impedance with a value of 50 Ω. The support offered by the CS evolutionary algorithm in this paper is that it helps in generating the best voltage excitations for minimizing the fitness function CF:

$$CF = wt_1 \cdot CF_1^2 + wt_2 \cdot CF_2^2 + wt_3 \cdot errorV \,, \tag{5}$$

where

$$CF_1 = \begin{cases} SLL_{ob} - SLL_d, & \text{if } SLL_{ob} > SLL_d \,, \\ 0, & \text{if } SLL_{ob} \geq SLL_d \end{cases} \,, \tag{6}$$

$$CF_2 = \begin{cases} WND_{\max ob} - WND_{\max d}, & \text{if } WND_{\max ob} > WND_{\max d} \,, \\ 0, & \text{if } WND_{\max ob} \geq WND_{\max d} \end{cases} \,. \tag{7}$$

If $VSWR_{\max} \leq 1.5$, then $errorV = 0$ else $errorV = \text{abs}(VSWR_{\max} - 1.5)$. The SLL_{ob} and SLL_d denotes the maximum obtained and desired SLL in decibels, $WND_{\max ob}$ and $WND_{\max d}$ denotes the maximum obtained and desired WND (between $u = 0.75$–0.80 in radiation pattern), in dB. Weights wt_1, wt_2, and wt_3 assign importance to the terms that are multiplied with them. In this paper, all the weights are substituted with a value of unity while generating original and corrected patterns.

3. Cuckoo Search Algorithm

The CS algorithm [7], [18]–[20] was introduced by Yang and Deb in 2010. It relies on the breeding behavior characteristics of cuckoos, as well as on the walking style of Lévy flights instead of the normal random walk. Before explaining the search technique that is based on the CS algorithm, an introduction to Lévy flight [20] needs to be done. Lévy flight is defined as a random walk with very large step lengths based on a heavy-tailed probability distribution. Cuckoos referred in this algorithm are classified as brood parasites that lay their eggs in the nests of other species of cuckoos and allow them to incubate their offspring. The host uses an adaptation principle in accordance with which it attempts to detect and reject other cuckoos' eggs. If the host cuckoo finds an egg belonging to another cuckoo, it throws the eggs out of the nest or destroys it altogether. This is the primary reason for which female cuckoos of certain species mimic the colors and patterns of eggs of a few host species in order to avoid their eggs being discarded by host cuckoos.

Here, the following rules [18] are considered before the search is commenced:

- each egg in a nest is considered to be a potential solution, as each cuckoo is laying one egg at a time, with that egg being stored in another nest in a random manner;
- the entry for the next generation will be the best nests with high quality eggs;
- the host bird discovers the cuckoo's egg with a probability $prob \in [0,\, 1]$. If found, it may throw away the egg away or build a new nest.

The third rule is approximated as a fraction of the total number of nests considered. The algorithm [18] is determined in the following manner:

Step 1. An initial population Cj $(j = 1, 2, \ldots, n)$ of n host nests is generated.

Step 2. Using Lévy flights, a random cuckoo is received and its fitness F_j is evaluated. Nest k is selected randomly.

Step 3. If the fitness $F_j \leq F_k$, then retain j as the solution or if the $F_j > F_k$, then replace j by k as the solution.

Step 4. The above process is continued by the abandonment of a fraction of worse nests and via Lévy flights, new nests are built at new locations. Then, the solutions are ranked and the current best result is obtained.

Step 5. Steps 2–4 of this algorithm are repeated until maximum generation is reached or a stop criterion is signaled.

Once the algorithm is run, the best nest is considered to be as the most optimum decision variable (voltage excitations) of linear antenna array elements.

For a cuckoo j, the new solutions are $c_j^{(t+j)} = c_j^t + \delta \oplus Lévy(\omega)$, where δ refers to the step size and $\oplus$ refers to the entry wise multiplications. The random step for Lévy flights is:

$$Lévy \sim u = t^{-\omega}, \quad 1 < \omega \leq 3 \,, \tag{8}$$

where ω refers to a parameter dealing with fractal dimension and t being the step size. The value of probability *prob* is 0.25 as used in [19].

4. Simulated Results

Two cases are discussed and the procedures for obtaining the original, damaged and corrected patterns of both the cases are given below.

4.1. Case 1: 36 Element Linear Antenna Array

Initially, the original radiation pattern for a 36-element linear antenna array is obtained by using the PSO [22]–[23] algorithm that is run for a total of 100 iterations. Four elements, namely 7, 19, 24 and 31, are assumed to be failed and the corresponding damage pattern is obtained. These failed elements are identified solely on a random basis. The failure of an element means that the value of voltage excitations across that element is zero. Now, both CS and PSO algorithms are run for 1000 iterations each and the outcomes of these algorithms are the newly generated voltage excitations of the remaining non-failed elements separately. Instead of generating 36 voltage excitation values, only 18 values have to be obtained, and these values are flipped left to obtain the remaining 18 values, giving the total of 36.

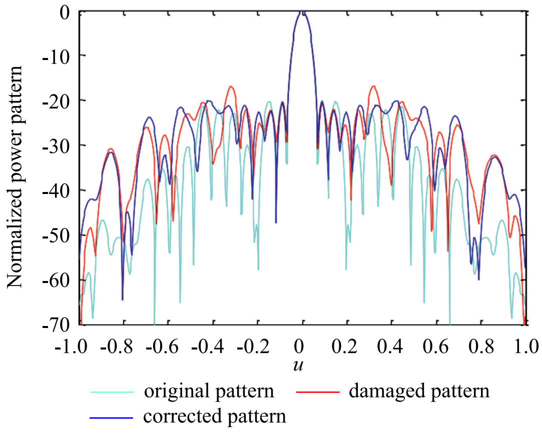

Fig. 2. Normalized original, damaged (four failures) and corrected power patterns using the CS algorithm. (For color pictures visit www.nit.eu/publications/journal-jtit)

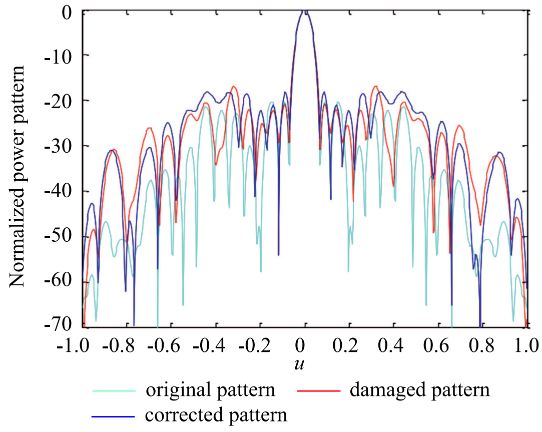

Fig. 3. Normalized original, damaged (four failures) and corrected power patterns using the PSO algorithm.

Moreover, the values of voltage excitations are designed to be between 0 and 1 while generating the original as well as the corrected pattern. The PSO that is used here is of the self-adjusting variety, with an additional inertia weight varying linearly from 0.9 to 0.5, and the learning factors are set to be 2.5. The program is written in Matlab. The total population that is used is 100 for both algorithms. The number of runs for each power pattern is maintained at up to 20 in order to avoid any impact on the results obtained by the initial values chosen by the algorithms.

In this paper, the expected maximum values of the parameters are as follows: SLL of -20 dB, VSWR of 1.5 and WND of -50 dB for a 36-elements antenna array, and SLL of -23 dB, VSWR of 1.5 and WND of -50 dB for a 120-elements antenna array. A failure of a dipole antenna means that its voltage excitation is zero. However, current flowing through the failed element is not zero and it behaves like a parasitic radiator.

Figures 2–3 show the normalized original, damaged and corrected power patterns using CS and PSO algorithms and Fig. 4 shows the amplitude distributions (voltage excitations) that are obtained for corrected power patterns using both algorithms.

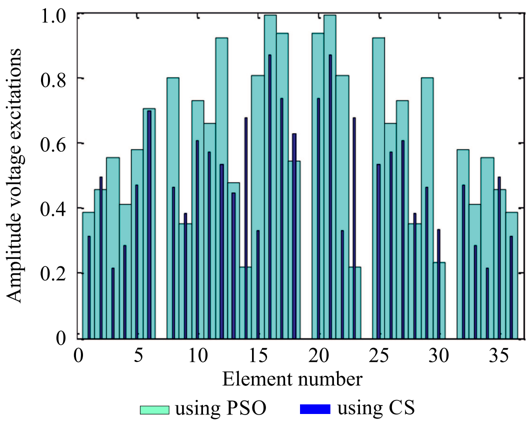

Fig. 4. Corrected voltage excitations vs. element number for case 1.

It is found that the CS algorithm successfully recovered both SLL and the WND values and produced a better value of VSWR when compared with the values produced by the PSO algorithm (Table 1). These values are obtained after the algorithms were run for 1000 iterations. Figure 5 shows the fitness values vs. the number of iterations obtained for the corrected pattern using both algorithms.

Figure 5 shows that even though the PSO and CS algorithms are, at the initial stages of the iteration, on par with

Table 1
SLL, WND and VSWR values of original, damaged and corrected normalized power patterns with four elements

Design parameters	Expected pattern	Original pattern	Damaged pattern	Corrected pattern	
				Using CS	Using PSO
SLL [dB]	–20	–20.2776	–16.8780	–20.0643	–18.1440
VSWR	1.5	1.3324	1.7292	1.5863	1.6350
Maximum WND [dB] ($u = 0.75$–0.80)	–50	–51.2919	–37.2187	–50.1628	–49.9102

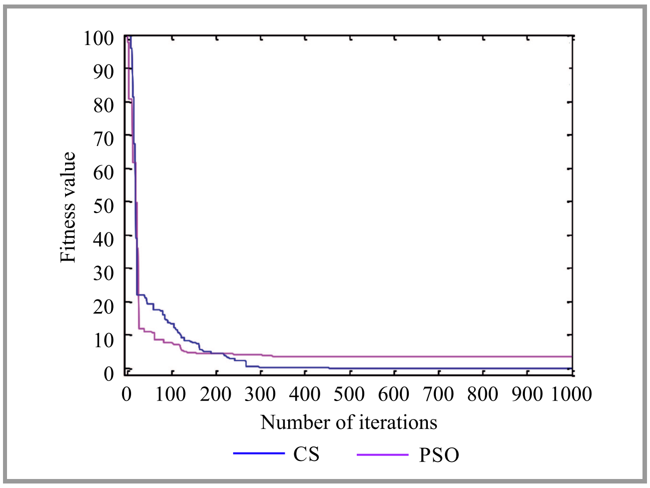

Fig. 5. Fitness value vs. number of iterations for corrected pattern generation for case 1.

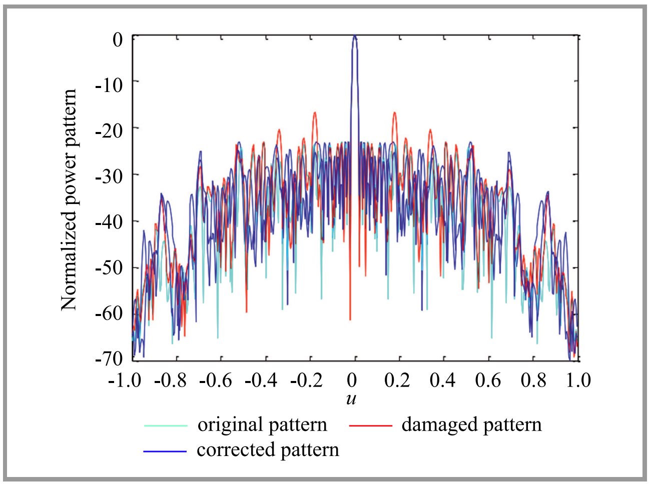

Fig. 6. Normalized original, damaged (10 failures) and corrected power patterns using the CS algorithm.

each other, CS converged very close to the final fitness value in the course of iterations, whereas PSO could not compete with the CS algorithm, which resulted in a high final fitness value. In other words, the CS algorithm produced the expected SLL and WND values within the given number of iterations. It also produced a VSWR value that was very close to the expected one, differing just by 0.0863. However, PSO did not produce any of the expected values in the corrected pattern.

4.2. Case 2: 120-Element Antenna Array

The same procedure that was presented in case 1 is followed here, except that the total number of elements considered is 120 with 10 failed components (6, 18, 30, 42, 54, 66, 78, 90, 102 and 114). Instead of generating 120 voltage excitation values, only 60 are necessary, due to symmetry. The total population used is 100 for both algorithms.

The measured computation times for case 1 and case 2, for the CS algorithm, are 2640 and 8197 s, and for the PSO algorithm, are 1331 and 4135 s.

Figures 6 and 7 show the normalized original, damaged and corrected power patterns using CS and PSO algorithms, while Fig. 8 shows voltage excitations that are obtained for the corrected power patterns.

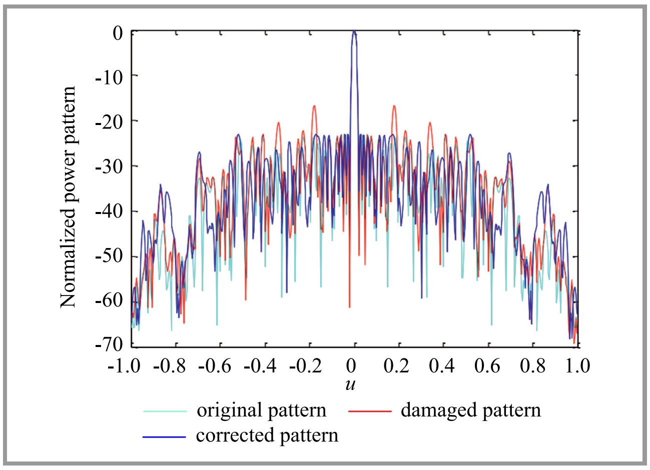

Fig. 7. Normalized original, damaged (10 failures) and corrected power patterns using the PSO algorithm.

The CS algorithm successfully recovered the SLL value and produced a better value of VSWR when compared with the PSO algorithm (Table 2). WND is recovered by both algorithms to the expected value. From both cases, it becomes quite evident that the CS algorithm produced better results than PSO. Figure 9 shows the fitness values vs. the number of iterations obtained for the corrected pattern.

Table 2
SLL, WND and VSWR values of original, damaged and corrected normalized power patterns with 10 bad elements (6, 18, 30, 42, 54, 66, 78, 90, 102 and 114)

Design parameters	Expected pattern	Original pattern	Damaged pattern	Corrected pattern	
				Using CS	Using PSO
SLL [dB]	–23	–23.005	–16.6057	–23.0922	–22.9855
VSWR	1.5	1.4864	1.8966	1.5776	1.6218
Maximum WND [dB] ($u = 0.75$–0.80)	–50	–50.059	–47.4189	–51.6059	–50.1379

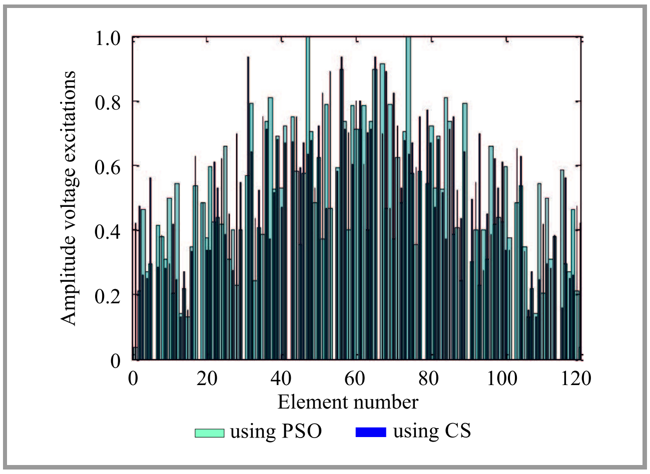

Fig. 8. Corrected voltage excitations vs. number of elements for case 2.

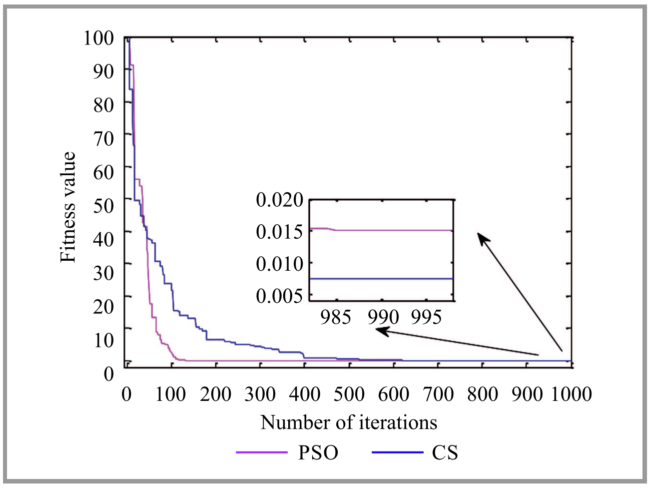

Fig. 9. Fitness value vs. number of iterations for corrected pattern generation for case 2.

A close look at the zoomed part of Fig. 9 shows that the CS algorithm produces a lower fitness value than PSO. It also shows that CS almost converged to the final fitness value, whereas PSO did not converge to reach such a level. In other words, one may say that the CS algorithm produced the expected SLL and maximum WND values, and slightly underperformed in terms of VSWR, by a margin of 0.0776. PSO ended up in producing the expected maximum WND, but could not produce the two remaining parameters. Moreover, its final VSWR value is higher than that produced by CS the algorithm, by a margin of 0.0442. All this shows that the CS algorithm is better than the PSO algorithm.

From the pattern obtained using the simulation, it is found that the purpose consisting in generating a corrected power pattern for the desired side lobe value, along with the wide null placement, is achieved and the error rate is lower in the corrected power pattern. Also, a better match between the antenna and feed network is provided by minimizing VSWR of the antenna elements. The VSWR obtained shows that the matching process is under control for the antenna elements of an array.

5. Conclusions

This paper demonstrated a successful utilization of the cuckoo search algorithm in failure correction of a linear array of 36 and 120 parallel dipole antennas with 4 and 10 corrupted elements. Based on the simulated results, it was found that the values of WND and SLL of the corrected pattern reached the expected values using the CS algorithm. It was also found that CS produced a better value of VSWR in comparison with the PSO algorithm, in both cases. A practical scenario has been considered in this paper, with the inclusion of mutual coupling effects. This algorithm and the objective function can be used for other antenna array geometries, such as a circular array, a planar array, etc. We are also working on the inclusion of the length of the antenna elements, as a design variable, for the purpose of achieving better performance of the antenna arrays in failure correction, and with the effect of the ground plane taken into consideration.

References

[1] R. S. Elliott, *Antenna Theory and Design*. Prentice-Hall, 2008 (ISBN: 978-0471449966).

[2] T. J. Peters, "A conjugate gradient-based algorithm to minimize the side lobe level of planar array with element failures", *IEEE Trans. on Antenn. and Propag.*, vol. 39, no. 10, pp. 1497–1504, 1991 (doi: 10.1109/8.97381).

[3] B. K. Yeo and Y. Lu, "Array failure correction with a genetic algorithm", *IEEE Trans. on Antenn. and Propag.*, vol. 47, no. 5, pp. 823–828, 1999 (doi: 10.1109/8.774136).

[4] J. A. Rodríguez, F. Ares, E. Moreno, and G. Franceschetti, "Genetic algorithm procedure for linear array failure correction", *Electron. Lett.*, vol. 36, no. 3, pp. 196– 198, 2000 (doi: 10.1049/el:20000236).

[5] W. P. M. N. Keizer, "Element failure correction for a large monopulse phased array antenna with active amplitude weighting", *IEEE Trans. on Antenn. and Propag.*, vol. 55, no. 8, pp. 2211–2218, 2007 (doi: 10.1109/TAP.2007.902008).

[6] B. K. Yeo and Y. Lu, "Fast array failure correction using improved particle swarm optimization", in *Proc. 2009 Asia Pacific Microw. Conf.*, Singapore, 2009, pp. 1537–1540 (doi: 10.1109/APMC.2009.5384420).

[7] R. Muralidharan, A. Vallavaraj, H. Patidar, and G. K. Mahanti, "Failure correction of linear array antenna with multiple null placement using cuckoo search algorithm", *ICTACT J. on Commun. Technol.*, vol. 5, no. 1, pp. 877–881, 2014 (doi: 10.21917/ijct.2014.0124).

[8] R. Muralidharan, A. Vallavaraj, H. Patidar, and G. K. Mahanti, "QPSO for failure correction of linear array antenna including wide null placement", *ICTACT J. on Commun. Technol.*, vol. 5, no. 3, pp. 959–962, 2014 (doi: 10.21917/ijct.2014.0137).

[9] H. Patidar, G. K. Mahanti, and R. Muralidharan, "Synthesis and Failure Correction of Flattop and Cosecant Squared Beam Patterns in Linear Antenna Arrays", *J. of Telecommun. and Inform. Technol.*, no. 4, pp. 25–30, 2017 (doi: 10.26636/jtit.2017.113417).

[10] H. Steyskal, R. A. Shore, and R. L. Haupt, "Methods for null control and their effects on the radiation pattern", *IEEE Trans. on Antenn. and Propag.*, vol. 34, no. 3, pp. 404–409, 1986 (doi: 10.1109/TAP.1986.1143816).

[11] Y. Lu and B. K. Yeo, "Adaptive wide null steering for digital beamforming array with the complex coded genetic algorithm", in *Proc. IEEE Int. Conf. on Phased Array Syst. and Technol.*, Dana Point, CA, USA, 2000, pp. 557–560 (doi: 10.1109/PAST.2000.859018).

[12] K. Guney and A. Akdagli, "Null steering of linear antenna arrays using a modified tabu search algorithm", *Progr. In Electromag. Res.* (*PIER*), vol. 33, no. 1, pp. 167–182, 2001 (doi: 10.2528/PIER00121402).

[13] H. Patidar and G. K. Mahanti, "QPSO for synthesis of linear array of isotropic antennas to generate flat-top beam including multiple null placement", in *Proc. Int. Conf. on Sig. Process. & Commun. ICSP 2015*, Noida, India, 2015, pp. 46–50 (doi: 10.1109/ICSPCom.2015.7150617).

[14] H. Patidar and G. K. Mahanti, "QPSO for synthesis of scanned linear array antenna for fixed side lobe level and first null beam width including wide null placement", in *Intelligent Computing and Applications Proceedings of the International Conference on ICA, 22-24 December 2014.*, D. Mandal *et al.*, Eds. *AISC*, vol. 343, pp. 197–204. Springer, 2015 (doi: 10.1007/978-81-322-2268-2_21).

[15] J. A. Rodriguez, F. Ares, and E. Moreno, "Feeding in-phase dipole arrays: a tutorial and a MATLAB program", *IEEE Antenn. and Propag. Mag.*, vol. 47, no. 5, pp. 169–173, 2005 (doi: 10.1109/MAP.2005.1599200).

[16] M. Thevenot *et al.*, "Synthesis of antenna arrays and parasitic antenna arrays with mutual couplings", *Int. J. of Antenn. and Propag.*, vol. 2012, Article ID 309728, pp. 1–22, 2012 (doi: 10.1155/2012/309728).

[17] G. K. Mahanti, S. Das, A. Chakrabarty, J. C. Brégains, and F. Ares, "Design of reconfigurable array antennas with minimum variation of active impedances", *IEEE Antenn. and Wirel. Propag. Lett.*, vol. 5, pp. 541–544, 2006 (doi: 10.1109/LAWP.2006.889557).

[18] X. S. Yang, *Nature-Inspired Metaheuristic Algorithms*. Luniver Press, 2008 (ISBN: 978-1-905986-10-1).

[19] X. S. Yang and S. Deb, "Engineering optimization by cuckoo search", *Int. J. on Mathem. Model. and Numerical Optimiz.*, vol. 1, no. 4, pp. 330–343, 2010 (doi: 10.1504/IJMMNO.2010.035430).

[20] X. S. Yang and S. Deb, "Cuckoo search via Lévy flights", in *Proc. of World Congr. on Nature & Biolog. Inspired Comput. NaBIC 2009*, Coimbatore, India, 2009, pp. 210–214 (doi: 10.1109/NABIC.2009.5393690).

[21] S. J. Orfanidis, "Electromagnetic Waves and Antennas", Rutgers University, 2008 [Online]. Available: www.ece.rutgers.edu/∼orfanidi/ewa

[22] J. Kennedy and R. C. Eberhart, "Particle swarm optimization", in *Proc. of IEEE Int. Conf. on Neural Netw. ICNN'95*, Perth, WA, Australia, 1995, vol. 4, pp. 1942–1948 (doi: 10.1109/ICNN.1995.488968).

[23] N. Jin and Y. R. Samii, "Advances in particle swarm optimization for antenna designs: Real-number, binary, single-objective and multiobjective implementations", *IEEE Trans. on Antenn. and Propag.*, vol. 55, no. 3, pp. 556–567, 2007 (doi: 10.1109/TAP.2007.891552).

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