Diagnosis of Faulty Elements in Array Antenna using Nature Inspired Cuckoo Search Algorithm

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Article Info	ABSTRACT
	Detection and correction of faulty elements in a linear array have great importance in radar, sonar, mobile communications and satellite. Due to single element failure, the whole radiation pattern damage in terms of side lobes level and nulls. Once we have detect the position of defective element, then correction method is applied to achieve the desired pattern. In this work, we introduce a nature inspired meta-heuristic cuckoo search algorithm to diagnose the position of defective elements in a linear array. The nature inspired cuckoo search algorithm is new to the optimization family and is used first time for fault detection in an array antenna. Cuckoo search algorithm is a global search optimization technique. The cost function is used as a fitness function which defines an error between the degraded far field power pattern and the estimated one. The proposed technique is used effectively for the diagnosis of complete, as well as, for partial faulty elements position. Different simulation results are evaluated for 40 elements Taylor pattern to validate and check the performance of the proposed technique.

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1. INTRODUCTION

The Array antennas have many applications in the field of sonar and communication. In large arrays, there is a chance of failure of one or more elements. The failure of a single element can degrade the sidelobe level and damage the null position. In most situations, it's not possible for us to replace the faulty element, however in such a condition we are adjusting the weights of the remaining elements to correct the damage pattern. In literature survey a variety of techniques are available for the detection and correction of damage pattern.

Once the position of faulty elements is detected then different methods for the correction of array is used. In [1] the symmetrical counterpart element passive technique along with hybrid computation is used to accomplish the required null depth level, null positioning at their previous location and low sidelobe level. The required pattern is achieved using symmetrical failure technique along with cultural differential evolution technique [2], [3]. In [4] the firefly algorithm is used for fault detection in linear array antenna. To locate the number and position of faulty element from the measured data of the fault free pattern and the damaged pattern [5] is used.

In this work the meta-heuristic cuckoo search algorithm is new to the optimization family and is used first time for fault detection in an array antenna. Cuckoo search algorithm is a global search optimization technique. The cost function is used as a fitness function which defines an error between the degraded far field power pattern and the estimated one. The proposed technique is used effectively for the diagnosis of complete, as well as, for partial faulty elements position. To provide the proper guiding principle for the users the paper is ordered as follow. The problem setup is discussed in section II, while in section III the proposed technique is provided. Section IV describes the simulations and the results while section V concludes the paper and proposes some future work.

2. RESEARCH METHOD

Consider a Classical Dolph Chebyshev (CDC) linear array of 40 elements along z-axis in which all the elements are positioned, equally spaced, non-uniform and the progressive phase excitation is given by the array pattern [6].

$$Array\,Factor(\theta_i) = \sum_{n=1}^{N} w_n \cos\left[kd\cos\theta_i(2n-1)/2+\gamma\right] \tag{1}$$

where w_n is the weight vector of the nth element, k is the wave number and γ is the progressive phase shift. Now we assume that w_m is failed in the array, by putting their weight w_m equal to zero in Equation (1). The faulty array pattern can be given by the following expression.

$$Array\,Factor_m(\theta_i) = \sum_{\substack{n=1\\n\neq m}}^{N} w_n \cos\left[kd\cos\theta_i(2n-1)/2+\gamma\right] \tag{2}$$

The far field pattern of the faulty element can be calculated in dB's by the following expression,

$$Q_d(\theta_i) = 10.\log_{10}\left(\sum_{\substack{n=1\\n\neq m}}^{N} w_n \cos\left[kd\cos\theta_i(2n-1)/2+\alpha\right]\right)^2 \tag{3}$$

The pattern of the faulty array can be obtained from Equation (1) by creating the excitation equals to zero to represent a complete faulty element. The (50%) partial fault element is equal to assume that their relative excitation equal to half of the original excitation. The fitness function in Equation (4) is minimized using CSA and to find the weights which generate the radiation pattern that is close to the measured one.

$$Fitness = \sum_{k=1}^{P}\left[\left|Q_d(\theta_k) - Q_o(\theta_k)\right|\right]^2 \tag{4}$$

Where P the number of samples used in the comparison, $Q_d(\theta_k)$ is the desired degraded array pattern and $Q_o(\theta_k)$ is the pattern obtained from CSA in P directions. This cost function compares the measured radiation pattern with the given arrangement of failed elements.

Meta-heuristic Cuckoo search algorithm is new optimization technique developed by Yang and Deb [7]. Optimization technique is very important and has many applications in every field of science and engineering. It has been proved in [8] that cuckoo search algorithm (CSA) has less number of parameters and computationally efficient than particle swarm optimization (PSO) and genetic algorithm (GA). In this paper, cuckoo search algorithm (CSA) is used first time for fault finding in array antenna, which has application in sonar and communications. The basic cuckoo search algorithm (CSA) has three idealized rules. (a) Each cuckoo lays only one egg at a time and dumps it in a randomly in a selected nest. (b) The best nests with high quality of eggs will carry over to the next generation. (c) The number of available host nests is fixed and the egg laid by a cuckoo is discovered by the host bird with a probability $p_a \in (0,1)$. This last assumption can be

approximated by a fraction p_a of the n host nests that are replaced by new solutions. In our work, the minimum of fitness function will give us the location of faulty element. When generating new solutions x_i^{t+1} for a cuckoo i, a Levy flight for the search capability is performed.

$$x_i^{t+1} = x_i^t + \alpha \oplus \text{Levy}(\lambda) \qquad (5)$$

where $\alpha > 0$ is the step size and depend on the problem of interest while $\oplus$ product represents the entry-wise multiplications. The Levy flight provides a random walk [9],

$$Levy(\lambda) = t^{-\lambda}, \quad (1 < \lambda \leq 3) \qquad (6)$$

3. RESULTS AND ANALYSIS

In this section, a Classical Dolph Chebyshev (CDC) linear array of 40 elements is considered for fault diagnosis using cuckoo search algorithm (CSA). The spacing between the elements is taken as $\lambda/2$. Analytical technique is used to find the weights of CDC for -30 dB side lobes level as shown in Figure 1. Complete and partial faults were made by making the weights of the faulty element either equal to zero or half of the original value correspondingly. For fault finding using CSA the parameters step size (α), population size (n) and rate of discovery (P_a) are used. The parameters are set to $\alpha = 1, n = 40$ and $P_a = 0.25$.

First we consider the case that sixth element in the array become damage and don't radiate. The diagnosis of fault in an array antenna is very important. If we don't know the exact location of faulty element, we cannot apply any correction method to recover the desired pattern. Due to sixth element failure, we obtain the black solid line pattern as shown in Figure 2. After optimization by nature inspired cuckoo search algorithm (CSA), we will find the pattern which is close to the black solid pattern as depicted in Figure 2 using the fitness function of Equation (4). The pattern obtained by CSA is shown in Figure 2 by the red dotted line which is nearly approachable.
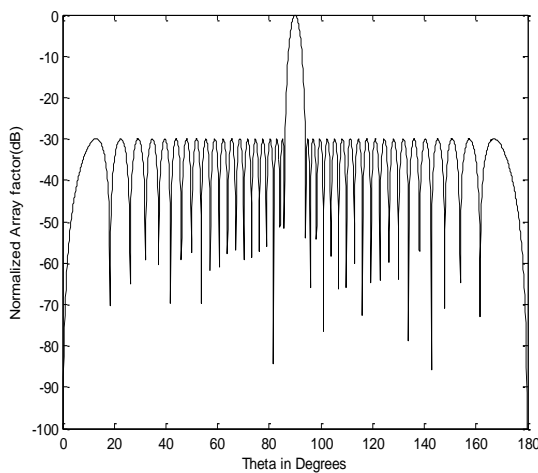

Figure 1. The power pattern of Classical Dolph Chebyshev array of 40 elements
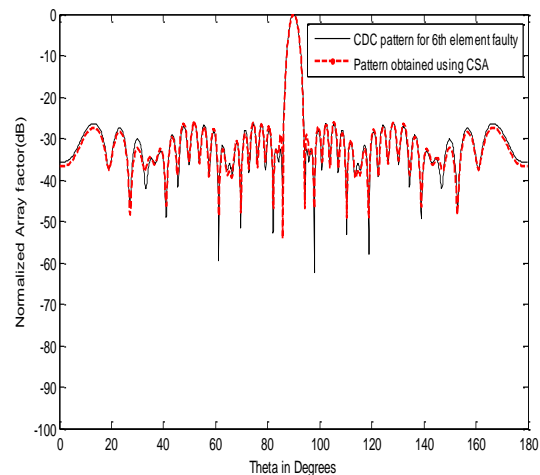

Figure 2. The faulty pattern of sixth element failure and pattern obtained using CSA

In the second case we assumed that 10th element in the array is partially damage (50%). The 10th element partially faulty pattern is shown in Figure 3 by the black solid line. After optimization by CSA, we

used the fitness function of Equation (4) and obtained the pattern for 10th element partial fault which is shown in Figure 3 by the red dotted line.

In the third case we assumed the complete as well as partial fault, in which 5th element is completely and the 11th element is partially faulty (50%). The CDC pattern for complete and partial fault is shown by the black solid line and after optimization by CSA, the pattern obtained is shown in Figure 4 by the red dotted line.
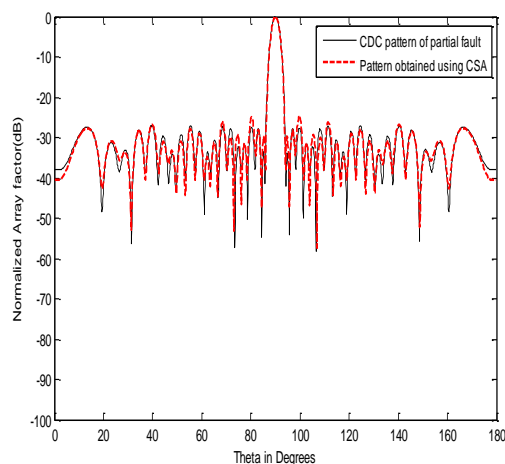

Figure 3. The 10th element partial fault pattern (50%) and pattern obtained using CSA.
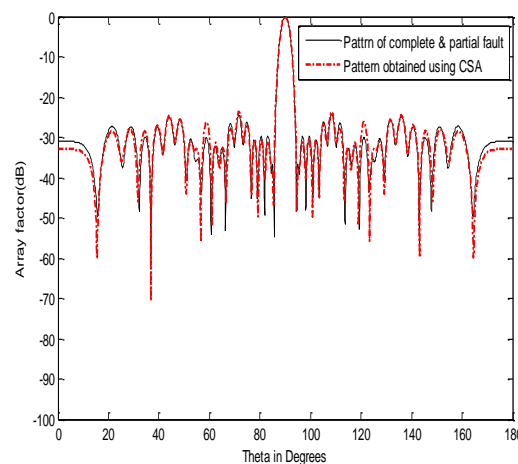
Figure 4. The CDC pattern for complete and a partial fault and pattern obtained using CSA

4.   CONCLUSION

The meta-heuristic cuckoo search algorithm (CSA) is tested first time for diagnosis of faulty element in array antenna. The proposed algorithm estimated the pattern and then compared with the faulty Classical Dolph Chebyshev (CDC) pattern and the minimum of the fitness function will give us the location of fully or partially faulty element. The method can be extended to L-type arrays.

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