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# Diagnosis of Faulty Sensors in Antenna Array using Hybrid Differential Evolution based Compressed Sensing Technique

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**ABSTRACT**

In this work, differential evolution based compressive sensing technique for detection of faulty sensors in linear arrays has been presented. This algorithm starts from taking the linear measurements of the power pattern generated by the array under test. The difference between the collected compressive measurements and measured healthy array field pattern is minimized using a hybrid differential evolution (DE). In the proposed method, the slow convergence of DE based compressed sensing technique is accelerated with the help of parallel coordinate decent algorithm (PCD). The combination of DE with PCD makes the minimization faster and precise. Simulation results validate the performance to detect faulty sensors from a small number of measurements.



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## 1. INTRODUCTION

Antenna arrays are commonly used in radars, microwave and satellites [1]. The array consist of a radiating elements. Therefore, the failure chance of one or more sensors increases as the array size increases. As a result, the pattern generated by the antenna is considerably damaged. Therefore, it is important to design an efficceint algorithm for the detection of defective elements before correction the patterns. The failure of sensor disturbs the pattern of the antenna array in terms of sidelobes and nulls [1], [2]. In normal scenario, the antenna array are located on the ground, the issue can be easily resolved by changing the defective elements but difficult to replace in case of satellite communications. In literature, there are numbers of available techniques for array detection [3], [4]. Although, these algorithms are expensive computationally because of the fact that these techniques require the same measurements as the number of sensors deployed in the antenna array.

In antenna array detection, the target is to diagnose the defective elements. Compressed sensing (CS) algorithm have benn developed for the detection of defective elements in the antenna community [5]. CS algorithms reduces number of linear measurements for the detection of defective elements in antenna array. The sparse vector is the difference of excitation weights of original antenna array and actual array [5]. In CS, sparsity in signals allows to under sample the signal i.e., below the Nyquist sampling criterion and small number of linear measurements in the signal consists the whole information compared with its dimensions, so the accurate diagnosis from a small number of linear measurements is possible [6]. The CS has applications in the field of magnetic resonance Imaging [7]. The measurement matrix should follow the restricted isometry property to avoid information in the signal from damaged. For the detection of the defective elements with high probability, the required number of linear measurements should be, where m number of linear measurements are required from an antenna array of length having the number of defective elements [5].

In this paper, a differential evolution based compressive sensing technique for detection of faulty sensors in linear arrays has been presented. This algorithms works from taking the linear measurements of power pattern generated by actual signal. The difference between the measured original reference antenna array field pattern and collected measurement is minimized using a hybrid Differential Evolution (DE) from compressive measurements. In the proposed method, the slow convergence of DE is accelerated with the help of Parallel Coordinate Decent algorithm (PCD). The combination of DE with PCD makes the minimization faster and precise. Simulation results of proposed compressed sensing based hybrid DE with PCD validate the detection of the faulty sensors performance from a less number of linear measurements. The rest of the article is organized as. The proposed solution is discussed in section 2. Section 3 states the numerical simulations, while section 4 concludes proposed work and recommended future direction.

## 2. RESEARCH METHOD

Consider an antenna array consist of $N$ number of radiating elements whose power patterns is given by [8]

$$ArrayFactor(\theta_i)=\sum_{n=1}^{N} w_n \cos\left[\left(\frac{2n-1}{2}kd\sin\theta_i\right)\right] \tag{1}$$

where $w_n$ is excitation weight of elements, the wave number is $k$, while the distance between the antenna element is $d$. The defective power pattern of the actual array is given by

$$ArrayFactor_m(\theta_i)=\sum_{\substack{n=1\\ n\neq m}}^{N} a_n \cos\left[\left(\frac{2n-1}{2}\right)kd\sin\theta_i\right] \tag{2}$$

where $a_n$ is nth excitation of the actual array. In (2), $a_n$ is given by,

$$a_n=\begin{cases}0 & \textit{with probability}\,\phi\\ w_n & \textit{otherwise}\end{cases} \tag{3}$$

where $\phi<1$ is fraction of defective elements. The refecene and decetive pattern with $N=16$ *and sidelobes level* $=-35dB$ are shown in Figure 1.The difference power pattern between the original and the actual array is given [5] by

$$p(\theta_i)=ArrayFactor(\theta_i)-ArrayFactor_m(\theta_i) \tag{4}$$

or it can be follows as

$$p(\theta_i)=\sum_{n=1}^{N} x_n \cos\left[\left(\frac{2n-1}{2}\right)kd\sin\theta_i\right] \tag{5}$$

where $p(\theta_i), i=1,2,3,...,K$ and $x_n$ is actual array vector is given by

$$x_n=w_n-a_n$$

To find the diagnosis problem in the antenna array, estimate the difference vector $\mathbf{x}_n$. In real situation, failures are very small as compared to the antenna sensors, thus the difference vector becomes sparse. The problem of diagnosis of defective elements can be reshaped in the frame of sparsness. The vector $\mathbf{p}$ is given to find the $l_o$-norm which follows the equation

$$\mathbf{p} - \mathbf{Ex} = \mathbf{r} \quad (6)$$

$$\mathbf{E} = \begin{bmatrix} \exp\left(jnkd\sin\theta_1\right)\cdots\exp\left(jNkd\sin\theta_1\right) \\ \vdots \quad \ddots \quad \vdots \\ \exp\left(jnkd\sin\theta_K\right)\cdots\exp\left(jNkd\sin\theta_K\right) \end{bmatrix}$$

where $\mathbf{E}$ is the measurement matrix [9]. If $\mathbf{E}$ is square matrix and invertible then through matrix inversion the unique solution can be found. In practical environment, the matrix $\mathbf{E}$ is ill-posed which is underdetermined. Thus to find the sparsest solution. Although, it has non-convex formulation as it involve $\binom{N}{S}$ exhaustive searches for the defective sensors.

$$\hat{x} = \arg\min_x \|p - Ex\|_2^2 \quad (7)$$

$$\hat{x} = \arg\min_x \|p - Ex\|_2^2 \quad subject\, to \|x\|_0 \le S \quad (8)$$

The $l_1$-norm is convex and provides sparsity in the proposed solution, while $l_o$-norm is not tractable nor convex. Therefore replace $l_o$-norm by $l_1$-norm as follows:

$$\hat{x} = \arg\min_x \left(\|p - Ex\|_2^2 + \|x\|_1\right) \quad (9)$$

Now to developed hybrid DE which uses the mutation operator and crossover procedures of the conventional algorithm. DE is a nature inspired evolutionary technique and was introduced by Storn and Price to solve real problems [10]. The differential evolution is stochastic based searche technique. Although the earlier convergence ofdifferntial evolution results in a higher possibility of searching near a local optimum. The algorithm is based on an operator called mutation, which adds an amount get by the difference of two randomly selected chromosomes of the population. Finding the difference between two randomly selected chromosomes from the current population, in fact the algorithm calculating the gradient in that region and this algorithm is an efficient way to self adaption the mutation operator. The iterative algorithm called PCD is used to adjust the second good solution in the current population when the fitness of the best chromosome remains the same during the iteration. This will help us the convergence issue related with the NP problem of (8). The update equation of PCD is given by the following expression,

$$x_k = x_{k-1} + \gamma\left(e_s - x_{k-1}\right) \quad (10)$$

where the constant $\gamma$ is estimated through line search. The initial value of proposed solution can be either an estimate of the least square solution or a zero vector. The term $e_S$ is computed as follows.

$$e_s = \rho_\beta\left(x_{k-1} + diag\left(E^T E\right)^{-1} E^T r_{k-1}\right) \quad (11)$$

Here $r_k = p - Ex_k$ is residue and $\rho_\beta$ represents the shrinkage operator

$$\rho_\beta(u) = \begin{cases} 0 & if \ |u| \le \beta \\ \left(\frac{|u| - \beta}{|u|}u \quad if\, |u| \ge \beta\right) \end{cases} \quad (12)$$

## 3. RESULTS AND ANALYSIS

In this simulation, consider a Chebyshev antenna array of 16 number of elements with element separation is used as test antenna. The pattern denotes -35 dB sidelobe level and nulls directed at desired angles as depicted in Figure 1. To check the results the power pattern is sampled in the interval of 10 degrees, 19 samples were taken from the damage power pattern. To check the validity of the proposed method, used the Matlab as a programming tool. At the instant, let us consider that the 3rd and 6th elements in the array become damage. Now to detect the location of faulty sensors, PCD algorithm is applied. After applying the PCD algorithm, the number and the location of defective elements is diagnosed. The blue (square) denote the Chebyshev original array weights, magenta (circle) shows defective elements and red (cross) the diagnosed fault which is shown in Figure 2. Similarly the same fault location is diagnosed with DE and hybrid DE with PCD. After applying the proposed DE hybridized PCD, the diagnosed fault is depicted in Figure 3 and Figure 4. By using the hybrid DE, location and number of defective elements precisely diagnosed than PCD and DE alone.

The mean square error (MSE) is computed for PCD, DE and hybrid DE. From Figure 5, it obvious that hybrid DE along PCD outperforms than DE and PCD alone.

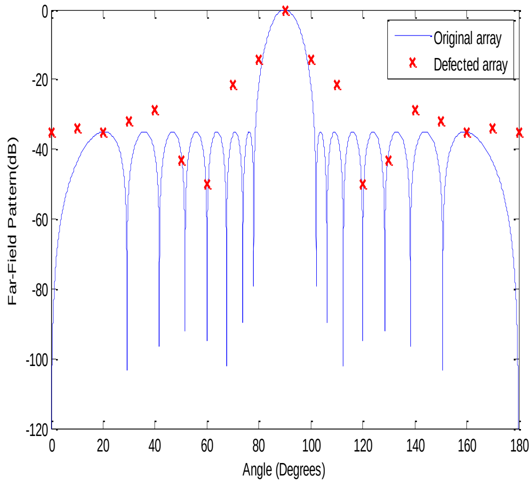


Figure 1. The original array and defective array with 3rd, 6th elements

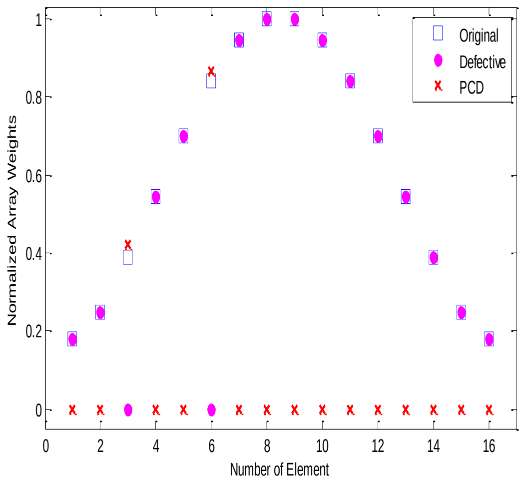


Figure 2. Diagnosis of defective elements with PCD algorithm

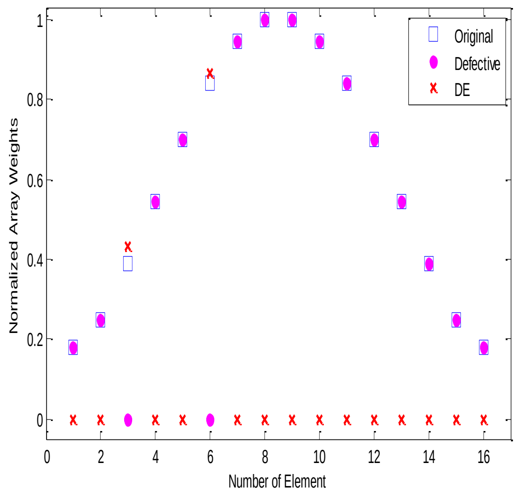


Figure 3. Diagnosis of defective elements with DE algorithm

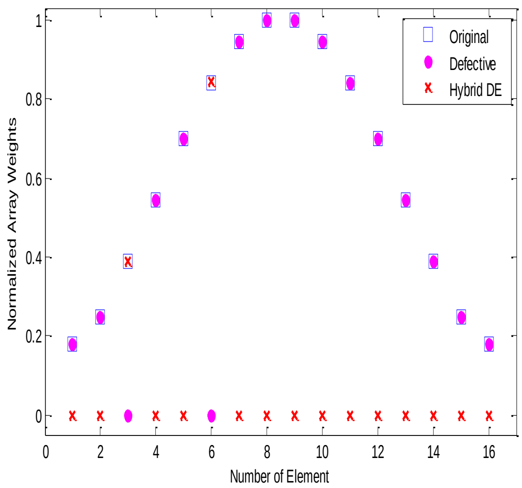


Figure 4. Diagnosis of defective elements with hybrid DE with PCD algorithm

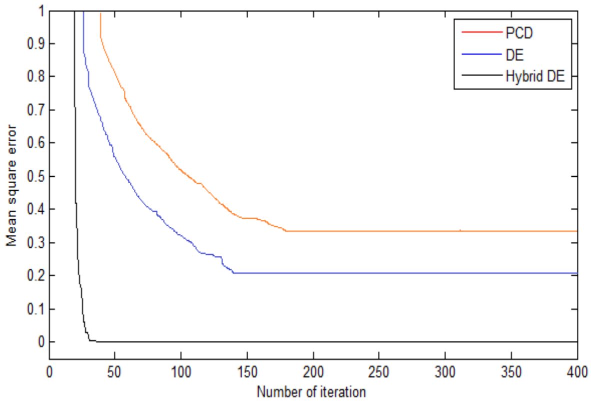


Figure 5. Mean square error of PCD, DE and hybrid DE

## 4. CONCLUSION

A compressed sensing based array detection algorithm have been developed. The array detection problem is formulated using a DE, PCD algorithm and further DE hybridized with PCD algorithm. These algorithms are designed for the detection of defective antenna elements and the numerical simulation confirm that the proposed hybrid algorithm gives accurate detection of defective sensors in antenna array with a small number of measurements. The slow and early convergence of DE is prohibited by hybridizing with PCD algorithm. The hybrid DE-PCD algorithm perform the diagnosis of defective elements more correctly then PCD and DE alone. This algorithm can be extended to circular arrays.

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## REFERENCES

[1] S. U. Khan, *et al.*, “Null Placement and Sidelobe Suppression in Failed Array Using Symmetrical Element Failure Technique and Hybrid Heuristic Computation,” *Progress In Electromagnetics Research B*, vol. 52, pp. 165-184, 2013.
[2] S. U. Khan, *et al.*, “Correction of Faulty Sensors in Phased Array Radars Using Symmetrical Sensor Failure Technique and Cultural Algorithm with Differential Evolution,” *The Scientific World Journal*, vol. 2014, 2014.
[3] J. A. Rodríguez, *et al.*, “Rapid method for finding faulty elements in antenna arrays using far field pattern samples,” *IEEE Trans. Antennas Propag.*, vol/issue: 57(6), pp. 1679-1683, 2009.
[4] S. U. Khan, *et al.*, “Application of firefly algorithm to fault finding in linear arrays antenna,” *World Applied Sciences Journal*, vol/issue: 26(2), pp. 232-238, 2013.
[5] M. D. Migliore, “A compressed sensing approach for array diagnosis from a small set of near field measurements,” *IEEE Trans. Antennas Propag.*, vol/issue: 59(6), pp. 2127-2133, 2011.
[6] M. Elad, “Sparse and redundant representations: from theory to applications in signal and image processing,” Springer, 2010.
[7] J. A. Shah, *et al.*, “A modified POCS-based reconstruction method for compressively sampled MR imaging,” *International Journal of Imaging System and Technology*, John Wiley & Sons, vol/issue: 24(3), pp. 203-207, 2014.
[8] R. J. Mailloux, “Phased Array Antenna Handbook,” 2nd ed, Norwood, MA, Artech House, 2005.
[9] S. Ji, *et al.*, “Bayesian compressive sensing,” *IEEE Trans. Signal Process*, vol/issue: 56(6), pp. 2346-2356, 2008.
[10] R. Storn and K. Price, “Differential evolution: a simple and efficient adaptive scheme for global optimization over continuous spaces, Technical Report TR-95-012,” International Computer Science Institute, Berkeley, USA, 1995.

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