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Detection of Defective Element in a Space Borne Planar Array with Far-Field Power Pattern Using Particle Swarm Optimization

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Abstract: *Particle swarm optimization technique is a soft computing approach that can be used in variety of engineering applications. In this paper the optimization technique viz., PSO is used in detection of defective element in space borne planar array. Detection of defective element in a space borne application requires optimized approach A calibration system can be used in satellite itself but in case of any failure, calibration can also be defective. So the good solution will be location of failing element from external data and optimization scheme can be used for the detection. PSO is used as a optimization tool that detects the defective element using power values that are being, received.*
Keywords: *PSO, IE3D, Planar-array (PA), Cost-function.*

I. Introduction

Particle swarm Optimization is used as optimization scheme for the detection of failed element in an array. A satellite has arrays with many elements and PSO optimization technique minimizes the cost function, which is difference of power error and fundamental power equation representing defective element in terms of position.

Now when any element is completely defective PSO is used to detect the defective location values and the result is compared with already designed values in order to find the defective element.

II. Particle Swarm Optimization

PSO is a population based iterative parallel search algorithm that models social behavior of a flock of birds. Since its introduction in [1], PSO has seen many modifications and has been adapted to different environments [2]. Many versions of PSO have been proposed and applied to solve optimization

problems in diverse fields [2]. PSO consists of a population (or a swarm) of s particles, each of which represents a potential solution. The particles explore an n-dimensional solution space in search of the global solution, where n represents the number of parameters to be optimized, x and y coordinates of a node this problem. Each particle i occupies a position Xid and moves with a velocity V_{id}, $1 \le i \le s$ and $1 \le d \le n$. Fitness of a particle is determined from its position in the search space. The fitness is defined in such a way that a particle closer to the global solution has higher fitness value than a particle that is far away. Each particle has a memory to store $pbest_{id}$, the position where it had the highest fitness, and gbest, the maximum of $pbest_{id}$ of all particles. The gbest particle represents the best solution found so far. At each iteration k, velocity vid and position Xid of each particle are updated using (1) and (2).

$$vid(k + 1) = w \cdot v_{id}(k) + c1 \cdot rand_1 \cdot (pbest_{id} - X_{id}) + c2 \cdot rand_2 \cdot (gbestd - Xid) \quad (1)$$

$$X_{id}(k + 1) = X_{id}(k) + v_{id}(k + 1) \quad (2)$$

Here, rand1 and rand2 are random numbers that range between 0 and 1 with a uniform distribution..

III. Implementation

Let us consider a planar array of N identical and equally oriented elements. Assuming that the elements are located over the x-y plane, the far field pattern, expressed in dB, can be calculated using the following expression [5]:

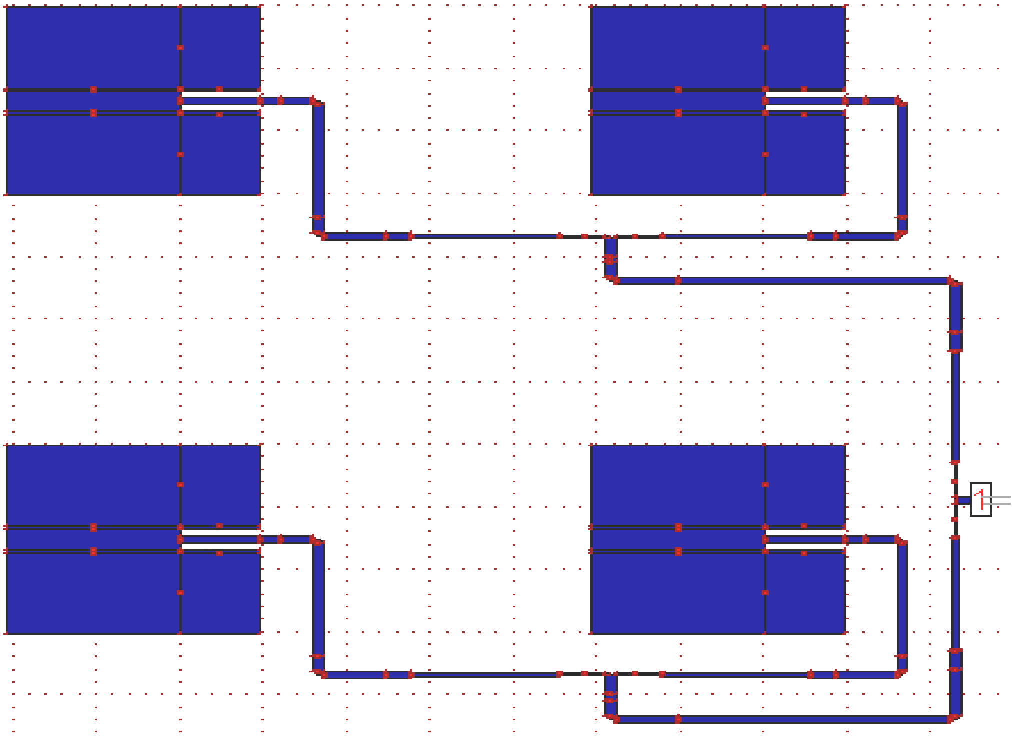
$$P(\theta,\phi) = 10\log_{10}(fe(\theta,\phi).\sum_{n=1}^{N} I_n e^{jk\sin\theta(x_n\cos\phi + y_n\sin\phi)})^2$$

Where I_n is the relative excitation of the n-element located at the position given by (x_n, y_n), fe(θ, φ) is the element pattern, and (θ, φ)gives the angular position of the field point [5-7].

Using a cost function, the method compares the Error in measured radiation pattern with that corresponding to the array with a given configuration of failed/correct elements. The optimization technique used is PSO. The minimization helps in detecting failed elements.

$$J = [P_{ERROR} - P(\theta, \phi)]$$

Where J is a cost function, P_{ERROR} is the value of error. P (θ, φ) is the value of the power pattern of element. $J = [P_{ERROR} - P(\theta, \phi)]$. The minimization of this cost function by means of PSO algorithm allows us to calculate that position where the value of error is equal to defective element power.



2X2 planar array is designed so x_n and y_n has specific value in the following equation,

$$P(\theta,\phi) = 10\log_{10}\left(fe(\theta,\phi). \sum_{n=1}^{N} I_n e^{jk\sin\theta(x_n\cos\phi + y_n\sin\phi)} \right)^2$$

Hence for space borne application there are two conditions.
1. Array network working properly.
2. Array network is damaged.

1) Array network working properly.

All the elements giving desired result and earth station gets the power which is matching with desired results, This means value of P_{ERROR} is equal to zero.

2) Array network damaged.

Earth station has far- field power pattern say P_8 when all the elements are working properly, and when there is fault in say any element & power of array is P_7

Then error is equal to

$$P_{ERROR} = P_8 - P_7$$

3) Applying Particle swarm Optimization optimization scheme.

Elements are taken and satellite array network is optimized and the optimization is working for two conditions.

4) Array working properly.

PSO when Array network working properly, In this case value of $P_8 = P_7 . P_{ERROR}$ is equal to zero, meaning thereby earth station is getting desired values.

5) Array not working properly.

Particle Swarm optimization when incorporated in array network, whose element is damaged, performs cost function minimization and gives position value where defective element is located.
The minimization is related to position , which means when minimization is achieved, position is noted which is the position of defective element.

6) Data from IE3D.

IE3D is used in antenna design, using IE3D ,2X2 planar array is designed. Far-field pattern is simulated using IE3D.Data when array working properly is taken, then damaging elements one by one the far field power value is noted. The error function, which is called Last function, is minimized using PSO.
Applying PSO, for minimization of cost function J.

$$J = [P_{ERROR} - P(\theta, \phi)]$$

Where,

$$P(\theta,\phi)=10\log_{10}(fe(\theta,\phi). \sum_{n=1}^{N} I_n e^{jk\sin\theta(x_n\cos\phi+y_n\sin\phi)})^2$$

Cost function has position parameter x_n and y_n. On minimization of cost function by PSO algorithm this leads to desired position of defective element. For testing any element is randomly made defective and the results are compared.

7) Results.

At frequency 3.8 GHz, we design 2x2 planar array and we get above data from IE3D, Radiated power from the array for various cases as designed from IE3D is as follows

ELEMENT	POWER RADIATED FROM ARRAY
ALL CORRECT.	0.00305787(W)
4TH INCORRECT.	0.00233863(W)
3rd INCORRECT.	0.00225029(W)
2nd INCORRECT.	0.00231477(W)
1st INCORRECT.	0.00218409(W)

Power radiated by elements for PA.

The value of error is calculated which means,
(When all 4-elements are correct, radiated power)-(When a element is incorrect, radiated power.) In other words,

$$P_{ERROR} = P_{correct} - P_{defective}.$$

Thus calculating the error by using the equation, we get the value of error.

ELEMENT	POWER (ERROR)
4TH INCORRECT.	0.00071924 (W)
3rd INCORRECT.	0.00080758(W)
2nd INCORRECT.	0.00074310(W)
1st INCORRECT.	0.00087378(W)

Error in power for PA.

Applying data to Particle swarm Optimization tool for planar array.

Now the PSO we take a function which is J

$J = [P_{ERROR} - P(\theta, \phi)]$ P_{ERROR} = Error arrived from IE3D and

$P(\theta,\phi)$ =Power equation of individual pattern.

Where

$$P(\theta,\phi)=10\log_{10}(fe(\theta,\phi). \sum_{n=1}^{N} I_n e^{jk\sin\theta(x_n\cos\phi+y_n\sin\phi)})^2$$

This means J has a value of,

$$J = (P_{error} - 10\log_{10}(fe(\theta,\phi).\sum_{n=1}^{N} I_n e^{jk\sin\theta(x_n\cos\phi + y_n\sin\phi)})^2)$$

In this equation we substitute the values of θ =45, ϕ =45, I_n =1, k=1, and then

$fe(\theta,\phi)$ Is calculated which as,

$fe(\theta,\phi) = 10^{(-\theta/82.16)}$, then we substitute the value of x_n and y_n as random position.

The aim of PSO is to minimize the value of J which means with minimization,

$$(P_{error} - 10\log_{10}(fe(\theta,\phi).\sum_{n=1}^{N} I_n e^{jk\sin\theta(x_n\cos\phi + y_n\sin\phi)})^2) \cong 0$$

This means,

$$P_{error} \cong 10\log_{10}(fe(\theta,\phi).\sum_{n=1}^{N} I_n e^{jk\sin\theta(x_n\cos\phi + y_n\sin\phi)})^2$$

so, PSO perform minimization and calculate position where it matches the result in this way x_n and y_n is calculated .These results are tabulated and compared when randomly a element is made defective.

The results are,

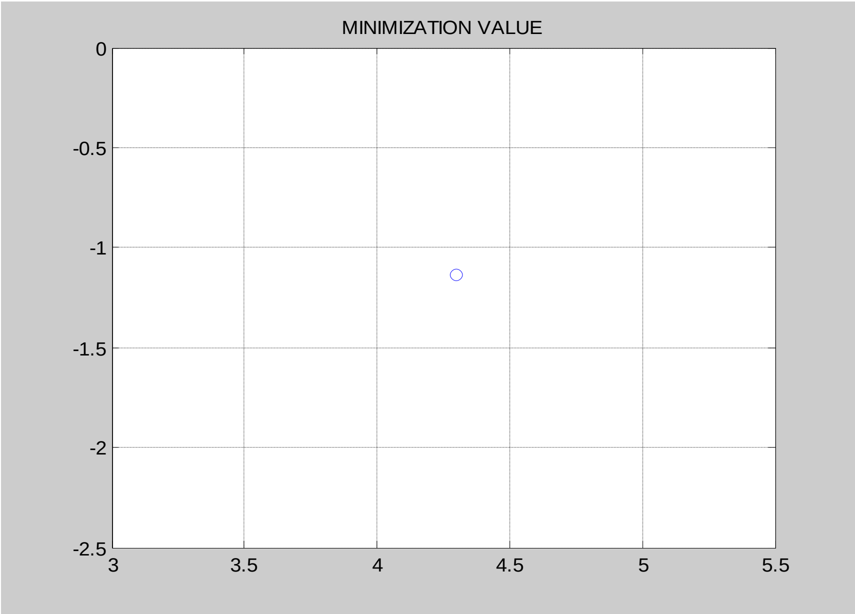
ELEMENT	POSITION X-AXIS	POSITION Y-AXIS
4TH INCORRECT.	3.9116	13.7609
3RD INCORRECT.	4.3138	14.8267
2ND INCORRECT.	5.6217	14.1233
1ST INCORRECT.	2.3821	14.2902

Table-6.21 Position arrived from BFA for PA.

Particle Swarm Optimization results

Fault in 4th element:-

To get started, select MATLAB Help or Demos from the Help menu.
ENTER THE VALUE OF ERROR =7.1924
Perror =
7.1924
ENTER THE VALUE OF THETA1 =45
theta1 =
45
fe1 =
0.2833
ENTER THE VALUE OF PHY1 =45
phy1 =
45
XAXIS =
3.9116
YAXIS =
13.7609
Enter the value of X-POSITION position3.9116
Enter the value of Y-POSITION position13.7609
ans =
**********************FAULT IN ELEMENT 4**************************
>>



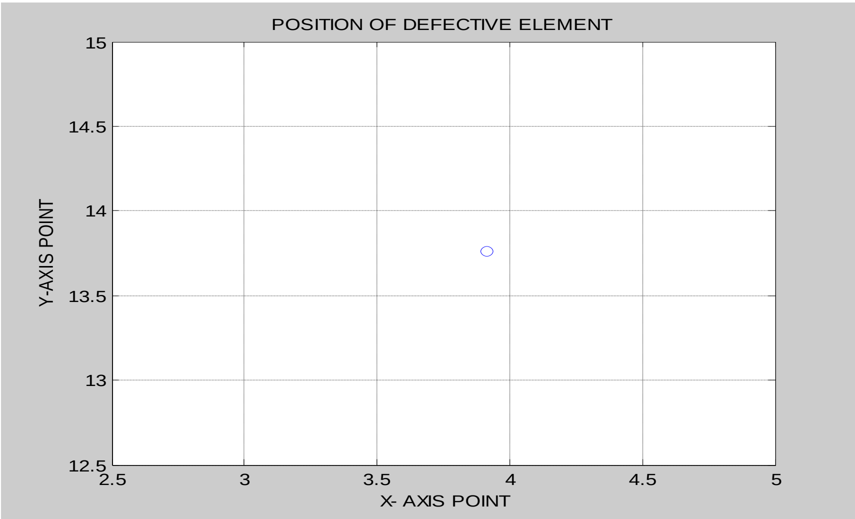


Figure 6.9 Position and minimization values for defective element 4 for planar array.

The results

Thus the results PSO are tabulated below.

DEFECT ELEMENT	ERROR	POSITION (X-AXIS)	POSITION (Y-AXIS)	O/P BFA
D4	7.1924	3.9116	13.7609	D4
D3	8.0758	4.3138	14.8267	D3
D2	7.4310	5.6217	14.1233	D2
D1	8.7378	2.3821	14.2902	D1

Results from PSO for PA.

The results from Particle swarm optimization scheme give the position that is value of x_n and y $_{n}$, which is in accordance to minimization of cost function J. The results when compared with designed values confirms that the PSO scheme can be used to find defective element in space borne array.

IV. Conclusions

The defective element detected is as desired. Thus this algorithm can be used to achieve optimization in space borne application involving numerous elements in an array. Detection of defective element using PSO tool with only far field power values make defective element detection easy with available data.

The results suggests that the defective element detection using Particle Swarm optimization tool on basis of only far – field power values is a great boon in all space borne applications involving array.

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