Design of 8-Element Linear Array with Practical Problem Diagnosis of Faulty Element Using Particle Swarm Optimization

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Abstract: Design of 8 element linear array as a model set up by ground best particle represents the best solution found so far. At each iteration k, velocity \(v_{id}(k)\) and position \(X_{id}(k)\) of each particle are updated using (1) and (2).

The paper intends to design 8 element arrays as a satellite model and making it element defective for diagnosis. Particle swarm optimization technique is used for the purpose of diagnosis. Detection of defective element in a satellite antenna requires optimized approach. A calibration system can be used in satellite itself but in case of any failure, calibration can also be defect. 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 an optimization tool that detects the defective element using power values that are being received.

Keywords: PSO, IE3D, Linear array (LA), Cost-function.

1. 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.

2. 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 \(X_{id}\) and moves with a velocity \(V_{id}\), \(1 \leq i \leq s\) and \(1 \leq d \leq n\). 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

Let us consider a Linear 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]:

\[
P(\theta, \phi) = 10 \log_{10}(1 + \sum_{n=1}^{N} I_n e^{jkx_n \sin(\theta) \cos(\phi)} e^{jyk_n \sin(\phi)})^2
\]

Where \(I_n\) is the relative excitation of the \(n\)-element located at the position given by \((x_n, y_n)\), \(fe(\theta, \phi)\) is the element pattern, and \((\theta, \phi)\) 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/corrected elements. The optimization technique used is PSO. The minimization helps in detecting failed elements.

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

Where \(J\) is a cost function, \(P_{\text{ERROR}}\) is the value of error. \(P(\theta, \phi)\) is the value of the power pattern of element.

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

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.

1. Design of 8 element Array
8 element Linear array is designed so $x_n$ and $y_n$ has specific value in the following equation,

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

Hence for Satellite application there are two conditions.

A. Array network working properly.
B. Array network is damaged.

A. 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.

B. 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

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

1. **Applying Particle swarm Optimization optimization scheme.**

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

2. **Array working properly.**

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

3. **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 $n$, which means when minimization is achieved, position is noted which is the position of defective element.

4. **Data from IE3D.**

IE3D is used in antenna design, using IE3D, 8 element Linear 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 $J$.

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

Where,

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

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.

5. **Results.**

At frequency 3.8 GHz, we design 8 element Linear array and we get above data from IE3D. Radiated power from the array for various cases as designed from IE3D is as follows

<table>
<thead>
<tr>
<th>ELEMENT</th>
<th>POWER RADIATED FROM ARRAY</th>
</tr>
</thead>
<tbody>
<tr>
<td>ALL CORRECT</td>
<td>0.00495341 (W)</td>
</tr>
<tr>
<td>8TH INCORRECT</td>
<td>0.00432779 (W)</td>
</tr>
<tr>
<td>7TH INCORRECT</td>
<td>0.00440877 (W)</td>
</tr>
<tr>
<td>6TH INCORRECT</td>
<td>0.00465102 (W)</td>
</tr>
<tr>
<td>5TH INCORRECT</td>
<td>0.00485793 (W)</td>
</tr>
<tr>
<td>4TH IN CORRECT</td>
<td>0.00482747 (W)</td>
</tr>
<tr>
<td>3RD IN CORRECT</td>
<td>0.00467427 (W)</td>
</tr>
<tr>
<td>2ND INCORRECT</td>
<td>0.00437555 (W)</td>
</tr>
<tr>
<td>1ST INCORRECT</td>
<td>0.00433651 (W)</td>
</tr>
</tbody>
</table>

**Power radiated by 8- elements for LA.**

The value of error is calculated which means, (When all 8-elements are correct, radiated power)-(When a element is incorrect, radiated power.) In other words,

$$P_{\text{ERROR}} = P_{\text{correct}} - P_{\text{defective}}$$

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

<table>
<thead>
<tr>
<th>ELEMENT</th>
<th>POWER (ERROR)</th>
</tr>
</thead>
<tbody>
<tr>
<td>8TH INCORRECT</td>
<td>0.00062562 (W)</td>
</tr>
<tr>
<td>7TH INCORRECT</td>
<td>0.00054640 (W)</td>
</tr>
<tr>
<td>6TH INCORRECT</td>
<td>0.00030239 (W)</td>
</tr>
<tr>
<td>5TH INCORRECT</td>
<td>0.00009548 (W)</td>
</tr>
<tr>
<td>4TH IN CORRECT</td>
<td>0.00012594 (W)</td>
</tr>
<tr>
<td>3RD IN CORRECT</td>
<td>0.00027914 (W)</td>
</tr>
<tr>
<td>2ND INCORRECT</td>
<td>0.00057786 (W)</td>
</tr>
<tr>
<td>1ST INCORRECT</td>
<td>0.00061690 (W)</td>
</tr>
</tbody>
</table>

**Error in power fo 8 element LA.**

**Applying data to Particle swarm Optimization tool for Linear array.**

Now the PSO we take a function which is $J$

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

Error arrived from IE3D and $P(\theta, \phi)$=Power equation of individual pattern.

Where
This means \( J \) has a value of,

\[
J = (P_{\text{error}} - 10 \log_{10}(\sum_{n=1}^{N} I_{n} e^{jk \sin \theta (x_{n} \cos \phi + y_{n} \sin \phi)})^2)
\]

In this equation we substitute the values of \( \theta = 45, \phi = 45, I_{n} = 1, \) \( k = 1, \) and then

\[
f(\theta, \phi) = I_{n} e^{(-82.16)}
\]

so, \( P_{\text{error}} \) 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,

<table>
<thead>
<tr>
<th>ELEMENT</th>
<th>POSITION(x10^{-4}mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>8TH IN incorrect.</td>
<td>13.7280</td>
</tr>
<tr>
<td>7TH IN correct.</td>
<td>14.2887</td>
</tr>
<tr>
<td>6TH IN incorrect.</td>
<td>14.3418</td>
</tr>
<tr>
<td>5TH IN incorrect.</td>
<td>14.0125</td>
</tr>
<tr>
<td>4TH IN correct.</td>
<td>13.5749</td>
</tr>
<tr>
<td>3TH IN correct.</td>
<td>13.6581</td>
</tr>
<tr>
<td>2ND IN incorrect.</td>
<td>14.7037</td>
</tr>
<tr>
<td>1ST IN correct.</td>
<td>14.5403</td>
</tr>
</tbody>
</table>

Table-6.21 Position arrived from BFA for LA.

Particle Swarm Optimization results

To get started, select MATLAB Help or Demos from the Help menu.

ENTER THE VALUE OF ERROR = 6.2562

Error = 6.2562

ENTER THE VALUE OF THETA = 45

Thetak = 45

fe1 = 0.2833

ENTER THE VALUE OF PHY1 = 45

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.

3. 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 suggest 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.

REFERENCES


