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Circular Antenna Array Pattern analysis using Radial Basis Function Neural Network

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Abstract. A method is proposed to design circular antenna array for the given gain and beam width using Artificial Neural Networks. In optimizing circular arrays, the parameters to be controlled are excitation of the elements, their separation, lengths and the circle radius. This paper deals about finding the parameters of radiation pattern of given uniform circular antenna array. Initially, the network is trained with a set of input-output data pairs. The trained network is used for testing. The training data set is generated from MATLAB simulation with number of elements $N=5$, 10, 15 and 20 elements of uniform circular array, respectively, distributed over a given circle, assuming 20 training cases. The number of input nodes, hidden nodes and output nodes are 20, 20 and 1, respectively. Predicted values of the neural network are compared with those of MATLAB simulation results and are found to be in agreement. This work establishes the application of Radial Basis Function Neural Network (RBFNN) for circular array pattern optimization. RBFNN is able to predict the output values with 97\% of accuracy. This work proves that RBFNN can be used for circular antenna array design.

1. Introduction
Circular array antennas are very popular due to several advantages such as an all-azimuth scan capability (i.e., the array can perform a 360\degree scan around its center), and ability to keep the beam pattern invariant. Circular array antennas contain many circular rings of different radii and with different number of elements. These arrays have several advantages, including flexibility in array pattern design and synthesis, in both [1] narrowband and broadband beam-forming applications. Circular arrays [2] are also favored in direction-of-arrival applications, since they provide almost invariant azimuth-angle coverage. This work establishes the application of RBFNN for circular array design optimization in antenna arrays. Its applications [6] span radio direction finding, air and space navigation, underground propagation, radar and sonar system.

The array factor for circular array is given in equation (1)

$$\text{AF}(\theta, \phi) = \sum_{n=1}^{N} I_n e^{jka[\sin \theta \cos(\phi - \phi_n) - \sin \phi \cos(\theta - \phi_n)]}$$

where $\theta_0$ and $\phi_0$ are the angles of the main beam, $a$ is the radius of the circular array and $I_n$ are the excitation coefficients of the elements.

In this work, a circular antenna array is considered, attention being on gain and beam width parameters. Artificial Neural Networks are implemented in designing a circular antenna array The
training data set is generated from MATLAB simulations with number of elements $N=5$, 10, 15 and 20 elements distributed along a given circle, assuming 20 training cases; the measured error is calculated from comparison of simulated values with the values generated using a Radial basis functions neural network.

![Figure 1: Geometry of N-element circular array.](image)

Figure 1 represents the geometry of N-element circular array antenna with the change in azimuth and elevation angles.

2. Artificial Neural Networks

Artificial Neural network is an application that alters certain variables in response to a set of corresponding input and output patterns. Beginning with an initial set [5] of internal values, the network modifies these quantities in order to find a position of “best fit,” thereby generating from the input patterns their expected results. The ability [7] of these networks to generalize relationships between inputs and outputs is a key to their effectiveness. RBFNN typically have three layers of neurons, namely input, hidden and output, which are fully interconnected as shown in Figure 2.

The first layer is composed of input nodes. An RBF network is a feed forward neural network with one hidden layer, with an RBF node function at each hidden node; the weight vector from the input layer to a hidden node is identified to the location of the center of the RBF for that node. The number of nodes, $n$, is equal to the dimension of input vector.

The second layer is a hidden layer composed of multivariate Gaussian nonlinear units that are connected directly to all of the input layer nodes. Each neuron in the hidden layer operates at the Gaussian transfer function. RBF network with a sufficiently large number of nodes can approximate any real multivariate continuous function on a compact set.
3. Algorithm steps
   - Input parameters of the uniform circular array are number of elements, element excitation, element spacing, and the element radius.
   - Determine the gain and beam width output parameters of array with ON/OFF mode of number of switching elements using MATLAB simulation
   - Training set consists of number of ON elements, gain and beam width as the inputs.
   - Excitation for corresponding element is determined for training the neural network
   - 20 data sets are considered for the network and out of which 15 sets of data samples are taken for training and 5 random data samples are considered as testing sets.
   - Compute the predicted values with the actual data values
   - Compute the change in mean average percentage error (measured error) for the technique

4. Results and Discussion
Consider a circular array with 5, 10, 15 and 20 elements respectively, the output parameters like in [4], gain and half power beam widths, being calculated. Figure 3 shows the radiation pattern for 5-element circular array generated using MATLAB simulation.

Figure 4 gives the resultant power pattern along φ cut corresponding to the circular path which finds the half power beam width (HPBW) for a 5-element circular array.

To establish the validity of the procedure, a circular array with 5 isotropic elements with uniform excitation and uniform spacing is considered. Table I gives the list of simulated output parameters of this circular array using MATLAB.
Table I. Parameters and Measured Error of Circular array (θ=0, φ=90)

| Input Parameters | Output Parameters (Simulated) | Predicted number of elements using RBFNN | % Measured error |
|------------------|------------------------------|-----------------------------------------|-----------------|
| **Elements**     | **Radius**                  | **Gain** | **HPBW** |                              |                             |
| 5                | 0.5                         | 6.0677 | 42.0203 | 5.0621 | 1.242                           |
| 10               | 0.5                         | 6.145  | 11.249  | 1.249                           |
| 15               | 0.5                         | 6.145  | 33.255  | 15.18  | 1.241                           |
| 20               | 0.5                         | 7.5258 | 33.255  | 20.25  | 1.244                           |

Mean average percentage error (MAPE) is calculated as (Observed value-Predicted value) / Predicted value, and the measured error calculated for the trained network data is as shown in Table I. Given simulated data is taken as the inputs for the training network and the number of elements are predicted using RBFNN algorithm. The samples are given as inputs to the neural network. Each network [5] is trained with 10 test patterns. During the training it is observed that only 20 input nodes are sufficient. Using more input nodes leads to more accurate representation of the pattern but will also require a much larger network and hence the computational time will increase. With the present architecture, the results indicate that for 97% of all cases presented, the network showed the correct result.

5. Conclusion
Patterns of circular antenna arrays are discussed with the selection of the elements using a Neural Network. Circular array pattern design and analysis is essential for multiple beam forming technique for antenna design. ANNs have better learning ability, generalization, parallel processing and error endurance attributes that lead to perfect solutions in applications where one needs to model the nonlinear mapping of complex data. This approach makes use of Neural Network that can be trained for any number of elements, spacing and excitation. Once the network is trained, it can find the parameters with respect to the input. Gain and half power beam width are the output parameters. Number of elements and radius of the ring are the input parameters for the training network. RBFNN is able to predict the output values with 97% of accuracy. The designed model of RBFNN has given quick speed of convergence and improved accuracy. This work proves that RBFNN can be used for circular array design.

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