Synthesis of Adaptive Antenna Array using Exponentially Weighted Recursive Least Square Algorithm

Glaret Subin P, Rathina Kumar P. and Muthu Krishnan P

Department of Electronics and Communication, SRM University, No.1, Jawaharlal Nehru Road, (100 feet Road, Near Vadapalani Signal), Vadapalani, Chennai - 600 026, Tamilnadu, India; glaretsubin@yahoo.co.in, rathan36@yahoo.co.in, muthu_eng05@yahoo.co.in

Abstract

Objective: Beam shaping is a powerful means to increase the capacity of antenna system in wireless communication for better transmission and reception of signal. Methods/Analysis: In this paper, an adaptive array arrangement is developed to improve beam shaping for better synthesis of antenna array system. The adaptive algorithm used here is exponentially weighted Recursive Least Square (RLS) algorithm which measures the correction weights by its own optimization which prevents the large inversion correlation matrix. Here the array of n antenna is connected to the adaptive controller which will take the decision whether the beam should access at a specific time. Novelty/Improvements: The convergence rate of mean square error is better here and the performance of RLS algorithm is better when compared to LMS algorithm. Proper beam formation can occur by using this method.

Keywords: Adaptive, Array, Beam, RLS, Weight

1. Introduction

For practical application of an antenna, the shape of the radiation pattern can be modified according to the desired radiation. Antenna system produces shaped beams like fanned beams, sector beams called shaped beam antenna. For example, fanned beams are used in surface search from air borne antenna. Such beams can be synthesized using antenna synthesis. In the antenna synthesis, current distribution is based on the radiation pattern. The synthesis of radiation pattern can be applied to a finite line source and an array of point sources. Line source is defined as a distribution of current along a line of finite length. Where as a linear array is a group of antennas arranged on the line with a finite spacing between them. The distribution of current in an antenna array is discrete and the array factor is in the form of finite summation. The major function in the practical antenna design is to find out the antenna configuration, excitation to produce narrow beam, low side lobes and decaying minor lobe. Fourier series method was first used for the antenna synthesis. Dolph mentioned a method based on the properties of chebyshev polynomials which produces maximum gain for a confirmal imposition of secondary lobes. Taylor modified the distribution of chebyshev polynomial by identifying gain restriction characteristics of huge arrays and proposed a refinement that enables minimum set of side lobes at the range of chebyshev design range beyond the nth pattern zero to decompose the inverse sine angle from the maximum level. Woodward Lawson method is used to synthesis beam pattern of desired shape. This method is based on the decomposition of excitation functions in to sum of uniform amplitude and linear phase sources. In Woodward Lawson method, array factor can be calculated at each sampling instant and the overall array factor will be addition of array factor of all sampling function. The pattern corresponding to such current components giving sampling functions which are sinc functions. In this paper an adaptive array system is optimized using exponentially weighted RLS
1.1 Model for Antenna System
Antenna system consists of n number of elements which are arranged in linear or circular as shown in Figure 1. and the weights of array elements are accommodated to overcome the channel characteristics in noisy environment. Proper decision to be taken which beam should be taken to ingress at specific time constructed on the system specifications. Beam formed adaptive system permit to steer the antenna beam to signals. The use of adaptive RLS algorithm with the fixed beam process draw the formation of beam ahead compared with other process which permits the manipulation of weights in the updated vector.

1.2 Fourier Series Method
Better Approximation can be obtained by sampling the distribution of line source with an array. Instead of sampling a line source, Fourier series can be applied directly to design an array. The number of point sources should be large enough to make a perfect beam shape. By enlarging the size of an antenna array enlarges the match between desired and actual beam shape. The desired pattern function SF (θ) can be expanded in to a Fourier series in between the limits –λ/2d and λ/2d.

\[
SF(\theta) = \sum_{m=-N}^{N} b_m e^{-jmd\sin\theta}
\]

Where m lies between –N and +N and

\[
b_m = \frac{d}{\lambda} \int_{-\lambda/2d}^{\lambda/2d} SF(\theta) e^{-jmd\sin\theta} d\theta
\]

which is the normalized amplitude distribution of the array.

Where d represents inter element spacing
θ denotes angle from broad side array
Practically infinite array is not possible. To overcome this, truncate the infinite series to a finite number of terms which produces the following approximation to

\[
SF(\theta) = \sum_{m=0}^{N-1} b_m e^{-jmd\sin\theta}/N
\]

Where m lies between 0 and N-1

![Figure 2. Space factor plot vs θ.](image)

The Spaced pattern for a line source using Fourier series method is shown in Figure 2

2. Woodward Lawson Method
Beam shaping for linear array can be done by using Woodward Lawson sampling method. Here the elements are arranged equally with proper spacing. The approximation of array for the line source is done by sampling the current distribution of the array element. The current generated by the element is given as

\[
A(x) = \frac{1}{N} b_m e^{-jx_m} \cos\theta_m
\]
The normalized amplitude distribution of the array is obtained from
\[ A(x) = \frac{1}{N} \sum_{m} b_m e^{-jx_m \cos \theta_m} \]  
(5)

Associated with each current source, the corresponding field pattern is
\[ SF(\theta) = b_m \sin(N \lambda d (\cos \theta - \cos \theta_m)/2))/(N \sin(N \lambda d (\cos \theta - \cos \theta_m)/2)) \]  
(6)

For a linear array, the corresponding field pattern is
\[ SF(\theta) = \sum(b_m \sin(N \lambda d (\cos \theta - \cos \theta_m)/2))/(N \sin(N \lambda d (\cos \theta - \cos \theta_m)/2)) \]  
(7)

Where \( b_m \) is excitation coefficient of each element of the array at its location, equal to the value of the specified pattern at the sample points
\[ b_m = SF(\theta = \theta_m) \]  
(8)

The Spaced pattern for a line source using Woodward Lawson method is shown in Figure 3.

2.1 Exponentially Weighted RLS Algorithm

In adaptive filtering method, the gradient decent algorithm is used for minimizing the means square error, that is \( \varepsilon(h) = \mathbb{E}[e(h)] \)

LMS Algorithm utilises steepest decent technique to enhance the vector weights. RLS Algorithm utilizes least squares technique to upgrade the weight vector, a least square error
\[ \varepsilon(h) = \sum_i |e(i)|^2 \]  
(9)

This requires no statistical information about the incoming signal and desired signal and may be directly evaluated from incoming signal and desired signal. The minimum mean square error is
\[ \varepsilon(h)_{\min} = \|z(h)\|_2 - r_{xx}^H(h)w_n \]  
(10)

Where \( |z(h)|_2 \) is the normalized weighing vector and
\[ z(h) = [z(h), z(h-1), ..., z(0)] \]  
(11)

For each value of \( h \), the solution in recursive form
\[ W_h = w_{h-1} + \Delta w_{h-1} \]  
(12)

Where \( \Delta w_{h-1} \) is a corrected weight at \( h-1 \).

\[ W_n = R_x^{-1}(h) r_{dx}(h) \]  
(13)

Where \( R_x(h) \) is the autocorrelation matrix of \( x(h) \).

Let \( F(h) = R_x^{-1}(h) \)

Gain vector is given by
\[ G(h) = \lambda^{-1} f(h-1)x'(h)/[1 + \lambda^{-1} f(h-1)x'(h)x'^T] \]  
(15)

\[ F(h) = \lambda^{-1}[F(h-1) - g(h)x'^T(h)F(h-1)] \]  
(16)

\[ g(h) = \lambda^{-1}[F(h-1) - g(h)x'^T(h)F(h-1)]x^*(h) \]  
(17)

\[ g(h) = F(h)x^*(h) \]  
(18)

\[ R_x(h)g(h) = x^*(h) \]  
(19)

To complete the recursion, the times modified equation are with respect to vector \( w_n \)
\[ W_h = w_{h-1} + g(h)[d(h) - w_{h-1}^T x(h)] \]  
(20)

\[ W_h = w_{h-1} + \beta(h)g(h) \]  
(21)

where \( \beta(h) = [z(h) - w_{h-1}^T x(h)] \)  
(22)

If \( \beta(h) \) is small, the current set of filter coefficients are close to their optimal values and a small correction needs to be applied to the coefficients.

3. Working Set Up of Antenna Array System

Arrived incoming signal direction which includes the interference signal and multipath signals are estimated. Then the user desired signal is spotted and extracted from the noisy input signal. Finally, beam is controlled in the path of the required signal which tracks the system
and nulls are placed at interference signals by the regular updating of complex weights. It is clear that the main beam radiation direction depends upon the difference in phase between the array elements. Consequently the direction of main beam is rotated in any direction by adjusting the difference in phase between the elements. This principle is used in the adaptive array system to enhance maximum radiation by adjusting the phase. In phased array antenna system Beam Formation is designed in the phase variation of -90 degrees to 90 degrees and has maximum voltage in the range of 0 to +1 V and the variable resistance 0 to 10 ohm to obtain high resolution.

4. Benefits of Antenna Array System

4.1 Reduction in Co-Channel Interference
Since the antenna array produces narrow beam radiation pattern which radiates in the desired direction and also produces in the unwanted direction, Co–channel interference is reduced.

4.2 Span Improvement
Since narrow beam of antenna array system produces high gain with same power for conventional antenna which leads to the improvement of span.

4.3 Frequency Utilization
Since Antenna arrays produces narrow beam which reduces co–channel interference, frequency can be utilized efficiently by many users.

4.4 Improved Efficiency
Antenna array system produces narrow beam which radiates in the desired direction which leads to the reduction of power wastage. This increases the efficiency of antenna array system.

5. Experiments and Results
A uniformly spaced linear antenna array with 30 elements and 0.5 degree and 60 degree interference angle of array is considered, where total number of data samples taken as 100. All the elements are uniformly excited with fixed amplitude values. Adaptive antenna array is optimized using RLS adaptive algorithm is shown in Figure 5.

Figure 4. MSE Pattern.

Figure 5. Optimized Power Pattern using RLS.

Figure 6. MSE Pattern using RLS.

Figure 4 and Figure 6. Represents the optimized power pattern of uniformly spaced array obtained using RLS and the MSE pattern where the error variation between the desired signal and array output signal obtained using RLS algorithm. In RLS Algorithm after 20th iteration the convergence between the array output and desired signal is clearly observed.
6. Conclusion

In this paper, an adaptive antenna array is synthesized by using exponentially weighted RLS algorithm. One of the drawbacks of LMS algorithm is having much iteration before satisfactory convergence is achieved. This problem was overcome by recursively calculating the required correlation matrix vector using RLS algorithm. Since the number of computation is more in RLS algorithm when compared to LMS algorithm it provides better response for co-channel interference. The rate of convergence is faster than LMS algorithm that is the convergence between the desired signal and array output is much faster.

7. References

1. Raju GSN. Pearson Education: Antennas and Wave Propagation. 2005.
2. Constantine A Balanis. New York: John Wiley & Sons, Inc.: Antenna Theory, 2nd ed. 1982.
3. Francois J, Essiben D, et. al. Design of non uniform linear antenna arrays using Dolph-Chebyshev and binomial methods. International Journal of Engineering Research and Applications. 2015; 5(8):187-95.
4. Godara L. Application of antenna arrays to mobile communications, Part-II: Beamforming and directional of arrival considerations. IEEE Proceedings. 1997; 85(8):1195-245.
5. Stutzman WL. Synthesis of shaped-beam radiation patterns using the iterative sampling method. IEEE Trans. Antennas Propagat. 1971 Jan; AP-19:36-41.
6. Yasin M, Pervez Akhtar. Performance Analysis of LMS and NLMS Algorithms for a Smart Antenna System. International Journal of Computer Applications. 2010; 4(9):25–32.
7. Geethanjali VS, Thushara Mohan and Srinivasa Rao I. Beamforming Networks to Feed Array Antennas. Indian Journal of Science and Technology. 2015; 8(S2):78–81.