

Study the Behavioral Change in Adaptive Beamforming of Smart Antenna Array Using LMS and RLS Algorithms

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Abstract-- In this paper we presents a brief outline about the adaptive beamforming of smart antenna array system which is consist of an antenna array elements with signal processing ability which is optimized using two distinct adaptive algorithms Least Mean Square (LMS) and Recursive List Square (RLS). The LMS is a gradient based approach. LMS algorithm uses the estimates of gradient vector from the given data. LMS incorporates an iterative procedure that makes successive corrections to the weight vector in the negative direction of the gradient vector which eventually leads to the minimum MSE. RLS algorithm used to compute the complex weights by its own simulation and also there is no longer necessary to invert a large correlation matrix. The recursive equations allow for easy updates of the inverse correlation matrix. These algorithms have been simulated using MATLAB 7.0.1 (R14) version software in Windows 7 environment. The simulation result shows the better adaptive algorithm through which we can obtain the optimum solution faster for smart antenna array systems.

Keywords: Smart Antenna Array, Beamforming, Adaptive algorithms, Least Mean Square (LMS), Recursive List Square (RLS).

I. INTRODUCTION

The phrase “Smart Antenna” usually refers to any array antennas, concluded in a worldly signal processor, which can adjust or adapt its own beam pattern in order to emphasize signals of interest and to minimize interfering signals. Smart antenna usually comprises both switch beam and beamformed adaptive system. Switched beam systems have several available fixed beam patterns. Beamformed adaptive system allows the antenna to steer the beam to any direction of interest while simultaneously nulling interfering signals. Smart antennas have alternatively been called digital beamformed (DBF) arrays [1] or adaptive arrays (when adaptive algorithms are used). Smart antenna patterns are controlled via algorithms based upon certain criteria. These criteria could be maximizing the signal-to-noise interference ratio (SIR), minimizing the variance, minimizing the mean square error (MSE), steering towards a signal of interest, nulling the interfering signals, or tracking a moving emitter to name a few. The implementation of these algorithms can be

performed electronically with the help of analog devices but it is usually more easily performed using digital signal processing. This requires that the array output be digitized through the use of an A/D converter. When the algorithms used are adaptive algorithms, this process is referred to as adaptive beamforming [11]. Adaptive beamforming is a sub category under the more general subject of digital

beamforming. The chief advantage of digital beamforming is that phase shifting and array weighting can be performed on the digitized data rather than by being implemented in hardware. On the receiver, the beam is formed in the data processing rather than literally being forming in space. Adaptive beamforming [9] requires sophisticated signal processing, which was considered too expensive for commercial applications. Recent efforts are being exerted to modify radar system to include adaptive beamforming techniques. An adaptive antenna array system is optimized using two distinct adaptive algorithms, LMS and RLS for our purpose to get the desired results.

II. MATHEMATICAL MODEL

A smart antenna system consists of a number of elements which are arranged in different geometries (like Linear, Circular, Time Modulated etc.) and whose weights are adjusted with signal processing techniques and evolutionary algorithms to exploit the spatial parameters of wireless channel characteristics under noisy environment. Smart antennas [2] generally encompass both switched beam and beam formed adaptive systems. Switch beam systems have several available fixed beam patterns. A decision is made as to which beam to access, at any given point in time, based upon the requirements of the systems. Beamformed adaptive systems allow the antenna to steer the beam to any direction of interest while simultaneously nulling the interfering signals. The smart antenna concept is opposed to the fixed beam “dumb antenna” which does not attempt to adapt its radiation pattern to an electromagnetic environment which is ever-changing in nature. In the past, smart antennas have alternatively been labeled adaptive arrays or digital beamforming arrays.

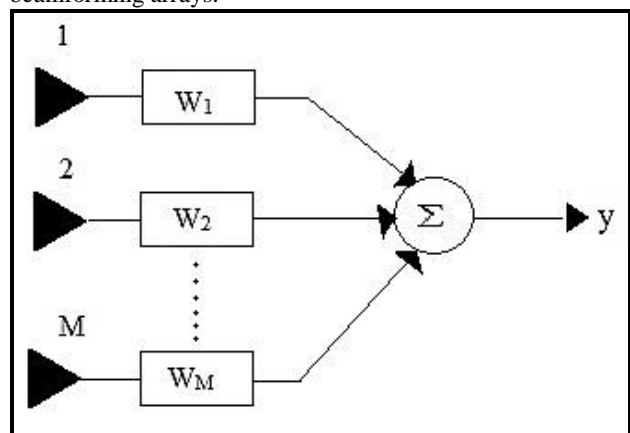


Figure.1: A traditional array configuration.

Two figures are depicts in here shows the constructional and operational behavioral difference, figure.1 shows a classical approach of antenna array configuration whereas in figure.2 shows a modified antenna array configuration.

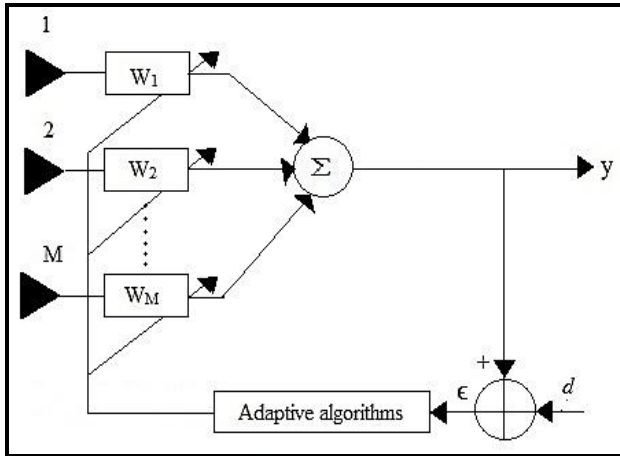


Fig.2: A smart antenna array configuration.

III. PROBLEM FORMULATION

We consider here an adaptive array arrangement for optimizing the smart antenna array. Adaptive beamforming [6], [8] generally more useful and effective beamforming solution because the digital beamformer merely consists of an algorithm which can dynamically optimizes the array pattern according to the change in the electromagnetic environment. Conventional array static processing systems are subject to degradation by numerous causes. The array SNR can be severely degraded by the presence of unwanted interfering signals. Beamforming [10] is generally accomplished by phasing the feed to each element of an array so that signals received or transmitted from all the elements in phase in a certain direction. The array factor for N element equally spaced linear array is given by,

$$AF(\theta) = \sum_{k=0}^{N-1} A_k e^{j(k(\frac{2\pi d}{\lambda} \cos(\theta) + \beta))} \quad (1)$$

Where, inter-element phase shift,

$$(\beta) = \frac{2\pi d}{\lambda} \cos(\theta_0)$$

A_k = wavelength.

θ_0 = desired beam direction.

d = inter-element spacing.

The output of the array $y(t)$ is the weighted sum of the received signals. $S_k(t)$ at the array elements and the noise $x(t)$ at the receiver which are connected to each array element. The weights iteratively computed based on the output array $y(t)$, are reference signal $r(t)$ that approximates the desired signal and previous weights. The reference signal is approximated to the desired signal using a spreading sequence.

The array output is given by,

$$y(t) = \omega^H x(t) \quad (2)$$

Where, ω^H denoted as the transpose of complex conjugate for the weight vector ω . In order to compute the optimum weights of the steering or array response vector from the sampled data of the array output has to be known. The array response vector is the function of incident angle as well as the frequency. The baseband received signal at the N^{th} antenna is sum of phase shifted and attenuated version of the desired signal $S_k(t)$.

$$X_n(t) = \sum_{k=1}^N \alpha_n(\theta_r) S_k(t) e^{-j2\pi f_c \tau_n + \beta_k} \quad (3)$$

The $S_k(t)$ is consist of both desired signal and the interfering signal. The beam former response can be expressed in vector form as,

$$r(\theta, \omega) = \omega^H a(\theta, \omega) \quad (4)$$

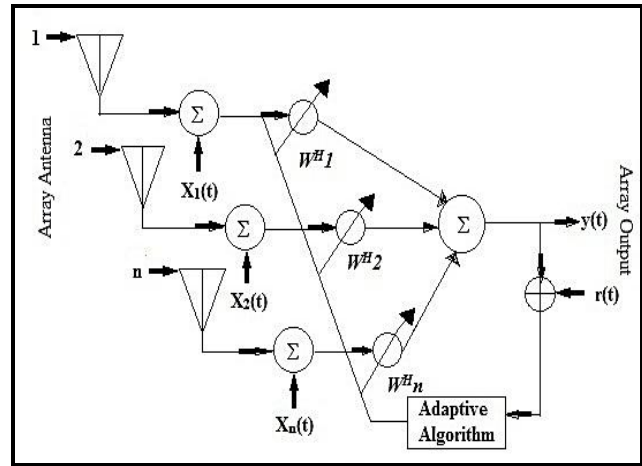


Fig.3: An adaptive antenna array system.

This equation is includes the possible dependency of a (θ) on ω as well. The proposed adaptive array configuration which is consist of the antenna array elements terminated in an adaptive processor which is designed to specifically maximize certain criteria as the emitters move or change, the adaptive array updates and compensates iteratively in order to track the changing environment.

IV. OVERVIEW OF LMS ALGORITHM

The Least Mean Square (LMS) algorithm [6] is an adaptive algorithm, which uses a gradient-based method of steepest decent. It uses the estimates of the gradient vector from the available data. It incorporates an iterative procedure that makes successive corrections to the weight vector in the direction of the negative of the gradient vector which eventually leads to the minimum mean square error compared to other algorithms. LMS algorithm is relatively simple .We can establish the performance surface (cost function) by again finding the MSE.

The solution for the weights is the optimum Wiener solution as given by

$$W_{opt} = \bar{R}^{-1} \bar{r} \quad (5)$$

Where \hat{R}_{xx}^{-1} =array correlation matrix.

\hat{r} = the signal correlation vector.

In general, we do not know the signal statics and thus must resort to estimating the array correlation matrix (\hat{R}_{xx}) and the signal correlation vector (\hat{r}) over a range of snapshots of for each instant in time. The instantaneous estimates of these values are given as

$$\hat{R}_{xx}^{-1}(k) \approx \hat{x}(k)\hat{x}^H(k) \text{ and}$$

$$\hat{r}(k) \approx d^*(k)\hat{x}(k)$$

If we substitute the instantaneous correlation approximation, we have the LMS solutions.

$$\begin{aligned} \bar{w}(k+1) &= \bar{w}(k) - \mu[\hat{R}_{xx}^{-1}\bar{w} - \hat{r}] \\ &= \bar{w}(k) + \mu e^*(k)\hat{x}(k) \end{aligned} \quad (6)$$

Where the error function is given by as

$$e(k) = d(k) - w^H(k)\hat{x}(k) \quad (7)$$

Where, $e(k)$ = error signal,

$d(k)$ = reference signal,

$$\hat{x}(k) = \hat{x}_s(k) + \hat{x}_i(k) + \hat{n}(k) \quad (8)$$

$\hat{x}_s(k)$ = desired signal vector.

$\hat{x}_i(k)$ = interfering signal vector.

$\hat{n}(k)$ = zero mean Gaussian noise for each channel.

V. OVERVIEW OF RLS ALGORITHM

Unlike the LMS algorithm which uses the method of steepest-descent to update the weight vector, the Recursive Least Square (RLS) algorithm uses the method of least square to adjust the weight vector [3],[8]. In the method of least squares, we choose the weight vector $w(k)$, so as to minimize a cost function that consists of the sum of squared errors over a time window. In the method of steepest decent, on the other hand, we choose the weight vector to minimize the ensemble average of the squared errors. In the exponentially weighted RLS algorithm, at time k , the weight vector is chosen to minimize the cost function

$$J(k) = \sum_{i=1}^k \lambda^{k-i} |e(i)|^2 \quad (9)$$

Where $e(i)$ is the error signal, and λ is a positive constant close to, but less than one, which determines how quickly the previous data are de-emphasized. In a stationary environment, however, λ should be equal to 1, since all the data past and present should have equal weight. The RLS algorithm is obtained from minimizing equation by expanding the magnitude squared and applying the matrix inversion lemma. The RLS algorithm can be describes by the following equations

$$l(k) = \frac{\lambda^{-1} p(k-1)x(k)}{1 + \lambda^{-1} x^H(k)p(k-1)x(k)} \quad (10)$$

$$z(k) = d(k) - w^H(k-1)x(k) \quad (11)$$

$$p(k) = \lambda^{-1} p(k-1) - \lambda^{-1} l(k)x^H(k)p(k-1)$$

The initial value of $p(k)$ can be set to, $p(0) = \delta^{-1}i$ (12)

Where i is the $m \times m$ identity matrix, and δ is a small positive constant called the regularization parameter, which is assigned with a small value for high SNR and a large value for low SNR. An important feature of the RLS algorithm is that it utilizes information contained the input data, extending back

to the instant of time when the algorithm is initiated. The resulting rate of convergence is therefore typically an order of magnitude faster than the simple LMS algorithm. The RLS algorithm also converges much more quickly than the LMS algorithm.

VI. RESULTS AND DISCUSSION

We consider here a linear array of 21 elements with inter-element spacing of 0.5λ , total number of data samples taken is 100. All the elements are uniformly excited. Smart antenna array is optimized using two distinct adaptive algorithms LMS and RLS.

Case 1: Optimization using LMS algorithms is shown below,

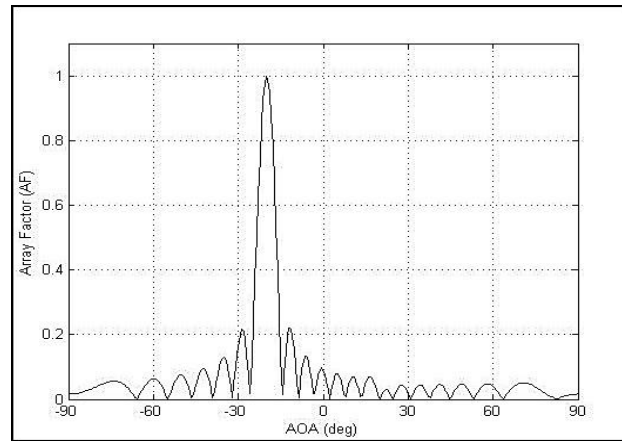


Fig.4: Array factor plot using LMS algorithm where $N=21$, interelement spacing= 0.5λ , desired user AOA= -20 deg, interferers AOA= 20 deg.

In case of fig.5, 6 we observed that after optimizing the adaptive or smart antenna array using least mean square algorithm the convergence of normalize weight and mean square error is obtained after the 50th number of iteration. So using LMS algorithm in adaptive beamforming of a smart antenna array to achieve the optimum solution it is taken more time than the RLS algorithm. Fig.4 represents the radiation pattern of the linear array using LMS.

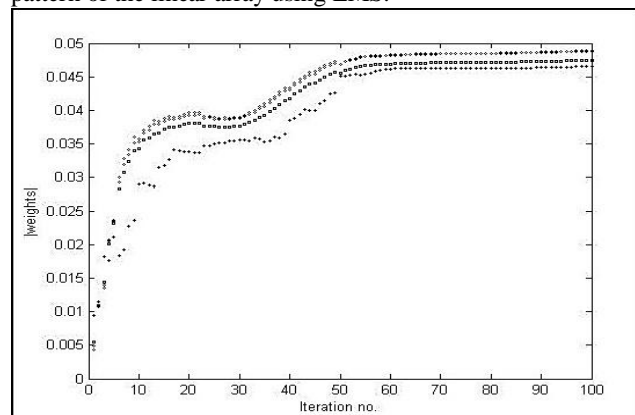


Fig.5: Normalized weight vector plot w.r.t iteration number obtained using LMS for desired user AOA= -20 deg. interferers AOA= 20 deg.

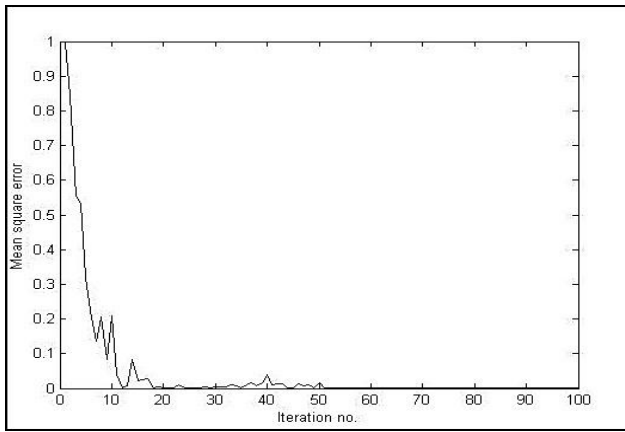


Fig.6: Mean square error plot obtained using LMS algorithms for AOA=-20 deg. interferers AOA=20 deg.

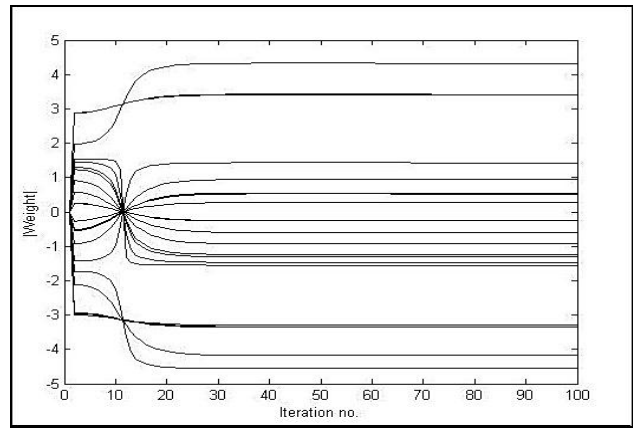


Fig.8: Normalize weight vector plot w.r.t iteration number obtained using RLS for desired user AOA=-20 deg. interferers AOA=20 deg.

Where in fig.8, 9, we observed that after optimizing the adaptive antenna array using recursive least square algorithm the convergence of normalize weight and mean square error is obtained after the 30th number of iteration. But using RLS algorithm in adaptive beamforming of a smart antenna array to achieve the optimum solution it is taken lesser time than the LMS algorithm. Fig.7 represents the radiation pattern of the linear array using RLS algorithm with desired signal direction at -20 degree and undesired signal direction at 20 degree, with interelement spacing 0.5 λ . All the element of the array is uniformly excited to achieve the optimum solution fast.

Case 2: Optimization using RLS algorithm is shown below,

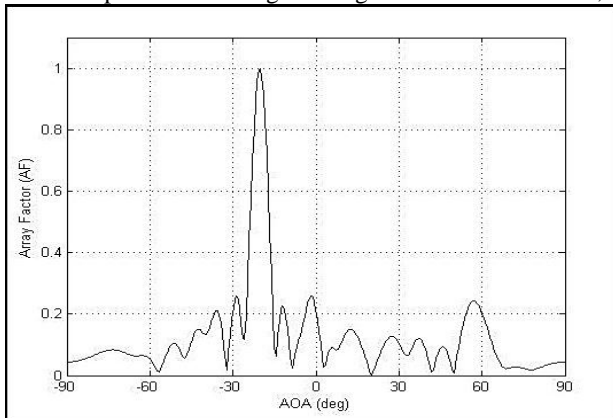


Fig.7: Array factor plot using LMS algorithm where N=21, interelement spacing=0.5, desired user AOA=-20 deg, interferers AOA=20 deg.

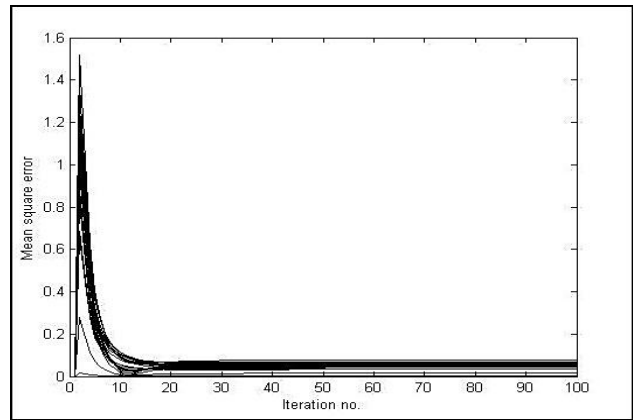


Fig.9: Mean square error plot obtained using RLS algorithms for AOA=-20 deg. interferers AOA=20 deg.

VII. CONCLUSIONS

In this paper a smart or adaptive array system is optimized using different adaptive beamforming algorithms such as LMS & RLS. The convergence speed of LMS algorithm depends on the eigen values of the correlation matrix. In an environment yielding an array correlation matrix with large eigen values spread it converges slowly in a dynamic channel environment. This problem is solved by the RLS algorithm. In both cases the reference signal is needed. Simulation results revealed that RLS algorithm involves more computations than the LMS algorithm; it provides better response towards co channel interference and safe side to the main lobe. It is also revealed that the convergence rate of RLS is faster than that of the LMS which can be visualized from the simulated results where we can see that when the adaptive or smart antenna array is optimized using LMS the convergence of normalize weight and mean square error is obtained after the 50th number of iteration, but in case of RLS convergence of normalize

weight and mean square error is obtained after the 30th number of iteration. So from the above results we can conclude that RLS algorithm shows better optimum solution than that of LMS algorithm.

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