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RESEARCH ARTICLE

Power pattern synthesis of smart antenna array using different adaptive algorithms

Somnath Patra*[1], Abhisek Pandey[2], Nisha Nandni[2], Sujeet Kumar[2], Vikky Jha[2], Monoj Kumar[2]
1. Asst. Prof. Department of ECE, Saroj Mohan Institute of Technology (Techno India Group), Hooghly.
2. Department of ECE & AEIE, Saroj Mohan Institute of Technology (Techno India Group), Hooghly.

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***Corresponding Author**

Somnath Patra

Abstract

Smart antenna array system is widely incorporate in wireless communication system; this paper presents a simulation based approach of smart antenna system for the performance evaluation of signal processing ability, which is optimized using different adaptive beamforming algorithms such as Least Mean Square (LMS) , Recursive List Square (RLS) and Simple Matrix Inversion (SMI). LMS is a gradient based approach, incorporates an iterative method which makes successive corrections to the weight vector to minimize the MSE. RLS algorithm is used to measure the complex weights by its own optimization thus there is no need to invert a large correlation matrix. SMI is defined as a time average estimate for the array correlation matrix using k^{th} time samples. After comparison of different parameters obtained using LMS, RLS and SMI, it's clearly observed that RLS algorithm is showing better performance also the convergence rate of MSE and NW is far better, which signifies the effectiveness of the proposed approach than other conventional optimization algorithms.

INTRODUCTION

Smart antennas have numerous benefits in wireless applications as well as sensors such as radar. In mobile wireless applications, smart antennas can provide a higher system capacity with a narrow beam towards the users of interest, while nulling other not interested users. This provides a high SNR, low power level, and permits greater frequency to reuse within same cell. This concept is called as SDMA. Smart antennas can be utilized to enhance direction-finding (DF) techniques by more accurately finding angle-of-arrival (AOA) [1-3]. A vast array of spectral estimation techniques can be incorporated, which are able to isolate the AOA with an angular precision that exceeds the array resolution. Smart antennas DF capabilities enhance the geo-location services by enabling a wireless system to better determine the location of a particular mobile user. Additionally, smart antennas can direct the array main beam towards signals of interest even when no reference signal or training sequence is available. This capability is called blind adaptive beamforming. Smart antennas usually consist of switch beam and beamformed adaptive system. A switched beam system operates on several fixed beam patterns. Beamformed adaptive systems have the capability to allow antenna, steer the beam to any direction of interest while continuously nulling interfering signals. Smart antennas also called as digital beamformed (DBF) arrays [4] or adaptive arrays (on depending upon the adaptive algorithms). Smart antennas power patterns are controlled via algorithms depends upon some specific criteria. These criteria could be maximizing the signal-to-noise interference ratio (SIR), minimizing the mean square error (MSE), minimizing the variance, steering towards a signal of interest, nulling the interfering signals, or tracking a moving emitter to name a few. When the algorithms used are adaptive in nature, this process is referred to as adaptive beamforming [5]. Adaptive beamforming requires an advanced signal processing technology, which was considered too expensive for commercial applications. Recent efforts are being exerted to modify radar system to include adaptive beamforming techniques for commercial usage. In this paper, an adaptive antenna array system is optimized using three distinct adaptive algorithms, LMS, RLS and SMI and after comparison the optimized results obtained from these algorithms, the best performed algorithm for the proposed approach will be discovered.

MATHEMATICAL MODEL

Smart antenna system consists of a number of elements arranged in Linear, Circular, Time Modulated or any other geometry and the weights of the array elements are accommodate with signal processing techniques and evolutionary algorithms to manipulate the spatial parameters of wireless channel characteristics under noisy environment. Smart antennas generally embrace both switched beam and beam formed adaptive array systems. Switch beam systems consist of 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 doi while simultaneously nulling the interfering signals. The smart antenna concept is opposed to the fixed beam arrangement which is termed as “dumb antenna” 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. The use of adaptive algorithm takes the fixed beamforming process one step further and allows for the calculation of continuously updated weights. The adaptation process must satisfy a specified optimization criterion.

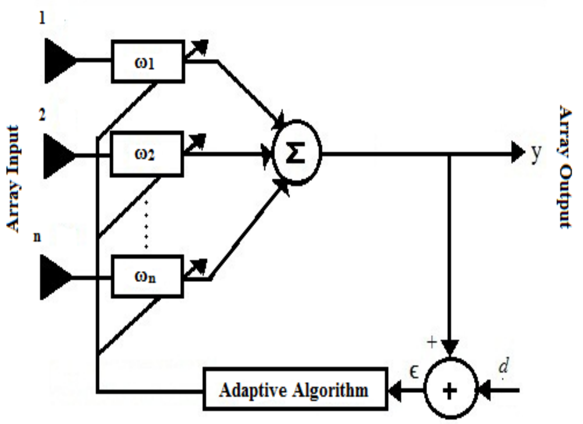

Fig 1. Conventional smart or adaptive antenna system.

PROBLEM FORMULATION

An adaptive array arrangement for optimizing the smart antenna array is considered here. Adaptive beamforming [6],[7] generally more useful and effective beamforming solution because the digital beamformer simply consists of an algorithm which can dynamically synthesize the array pattern according to the change occurs in the electromagnetic environment. Conventional static array processing systems are subject to downcast by various causes. The array SNR can be seriously degraded by the presence of unwanted interfering signals. Beamforming [8] is generally accomplished by phasing the feed to each element of an array so that signals transmitted or received from all the elements in phase in a certain direction. The array factor for *N* element equally spaced linear array is given by,

$$AF_n(\theta)=\sum_{K=0}^{N-1}A_k\, e^{\left(ik\left(\frac{2\pi d}{\lambda}\cos(\theta)+\beta_d\right)\right)} \qquad (1)$$

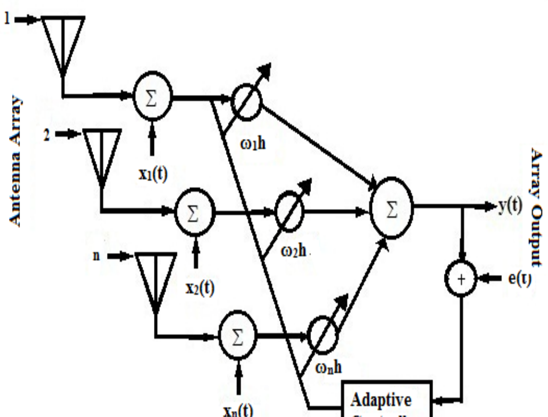

Fig 2. A modified smart or adaptive antenna array arrangement.

Where, inter-element phase shift,

$$(\beta_d) = -\frac{2\pi d_x}{\lambda_d}\cos(\theta_d)$$

λ_d = Desired wavelength.

θ_d = Desired beam direction.
d_x = Inter-element spacing.
The array output *y (t)* is the weighted sum of the received signals. *$S_n(t)$* 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)*, the reference signal *e(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,

$$y(t) = \omega_n^h * x(t) \tag{2}$$

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 *$S_n(t)$*.

$$X_n(t) = \sum_{K=1}^{N} a_n(\theta_n) S_n(t) e^{-j2\pi f_c \tau_n \theta_n} \tag{3}$$

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

$$r(\theta,\omega) = \omega_n{}^h * a(\theta,\omega) \tag{4}$$

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.

OVERVIEW OF LMS ALGORITHM

The Least Mean Square (LMS) algorithm is a gradient-based method of steepest decent. Monzingo [5-9] gives an excellent fundamental treatment of this approach. Gradient based algorithms assume an established quadratic performance surface. LMS uses the estimates of the gradient vector from the available data and incorporates an iterative procedure for successive corrections to the weight vector in the direction of the negative of the gradient vector which eventually leads to the minimum MSE compared to other algorithms. LMS algorithm is relatively very easy to implement .We can establish the cost function by again finding the MSE. The error, as indicated is,

$$\varepsilon(k) = d(k) - \bar{w}^H(k)\bar{x}(k) \tag{5}$$

The squared error is given as

$$|\varepsilon(k)| = \left|d(k) - \bar{w}^H(k)\bar{x}(k)\right|^2 \tag{6}$$

The cost function is given as

$$j(\bar{w}) = d - 2\bar{w}^H\bar{r} + \bar{w}^H\overline{R_{xx}}(\bar{w}) \tag{7}$$

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

$$\overline{w_{opt}} = \bar{R}_{xx}^{-1}\bar{r} \tag{8}$$

Where $\bar{R}_{xx}^{-1}$ = Array correlation matrix.
$\bar{r}$ = the signal correlation vector.
In general, we do not know the signal statics and thus must resort to estimating the array correlation matrix ($\overline{R_{xx}}$) and the signal correlation vector ($\bar{r}$) over a range of snapshots of for each instant in time. The instantaneous estimates of these values are given as

$R_{xx}(k) \approx \bar{x}(k)\overline{x^H}(k)$ &

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

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

$$\bar{w}(k+1) = \bar{w}(k) - \mu\left[R_{xx}\bar{w} - \hat{r}\right] = \bar{w}(k) + \mu e^{*}(k)\bar{x}(k) \tag{9}$$

Where the error function is given by as
e(k)= d (k)- $w{*}h(k)\bar{x}$ (k)

Where, e(k) = Error signal,
d (k) = Reference signal,
$\bar{x}$ (k) = $\overline{x_s}$ (k) + $\overline{x_i}$ (k)+ $\bar{n}$ (k)
$\overline{x_s}$ (k) = Desired signal vector.
$\overline{x_i}$ (k) = Interfering signal vector.
$\bar{n}$ (k) = Zero mean Gaussian noise for each channel.

OVERVIEW OF RLS ALGORITHM

LMS algorithm uses the method of steepest-decent to update the weight vector [4-10], even though the SMI method is more faster than the LMS algorithm, the computational burden and potential singularities can cause problem, the Recursive Least Square (RLS) algorithm uses the method of least square to adjust the weight vector . 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

$$j(k) = \sum_{i=1}^{k} \lambda^{k-1} \left|e(i)\right|^{2} \tag{10}$$

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

$$l(k) = \frac{\lambda^{-1} p(k-1) x(k)}{1 + \lambda^{-1} x^{H}(k) p(k-1) x(k)} \tag{11}$$

$$\varepsilon(k) = d(k) - w^{H}(k-1) x(k) \tag{12}$$

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

The initial value of *p(k)* can be set to, $\mathrm{p}(0) = \delta^{-1} i$ (13)

Where *i* is the m*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.

OVERVIEW OF SMI ALGORITHM

LMS adaptive scheme has several drawbacks that the algorithm must go through many iterations before satisfactory convergence is achieved. If the signal characteristics are rapidly changing, the LMS algorithm may not allow tracking of the desired signal in a desired manner. The rate of convergence of the weights indicated by the eigen value scattered in the array correlation matrix. One possible approach to circulating the relatively slow convergence

of the LMS scheme is by use of SMI method [5], [15]. The sample matrix is a time average estimate of the array correlation, matrix using Kth-time samples.
The optimum array weights are given by the optimum Wiener solution as

$$\overline{w_{opt}} = \bar{R}_{xx}^{-1}\bar{r} \tag{14}$$

Where $\overline{R_{xx}} = E[\bar{x}\cdot\overline{x^H}]$, $\bar{r} = [d^{*}.\ \bar{x}]$
We can estimate the correlation matrix by calculating the time average such that,

$$R_{xx} = \frac{1}{k}\sum_{k=1}^{k}\bar{x}(k)\bar{x}^{H}(k) \tag{15}$$

Where, K is the observational interval.
The correlation vector can be defined as

$$\hat{r} = \frac{1}{k}\sum_{k=1}^{k} d^{*}(k)\bar{x}(\mathrm{k}) \tag{16}$$

The SMI weights can be calculated as

$$\overline{w_{SMI}}(k) = \overline{R_{xx}^{-1}}(k)\bar{r}(k) \tag{17}$$

RESULTS AND DISCUSSION

A uniformly spaced linear antenna array with 30 elements and 0.5λ inter-element spacing with desired AOA = 0 deg. and interferer AOA= 60 deg. is considered, where total number of data samples taken as 100. All the elements are uniformly excited with fixed amplitude values. Smart or adaptive antenna array is optimized using three distinct adaptive algorithms LMS, RLS, SMI. In Case I, fig 3 , fig 4. represents the optimized power pattern of uniformly

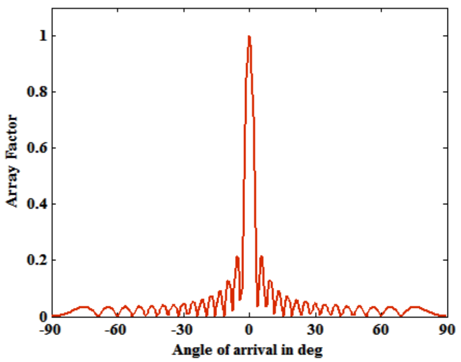

Fig 3. Optimized power pattern obtained using LMS

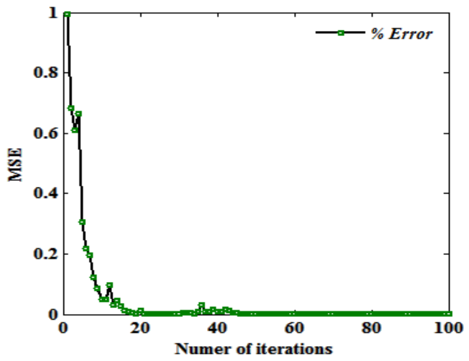

Fig 4. MSE pattern with desired AOA=0 deg. and interferer AOA=60 deg. obtained using LMS

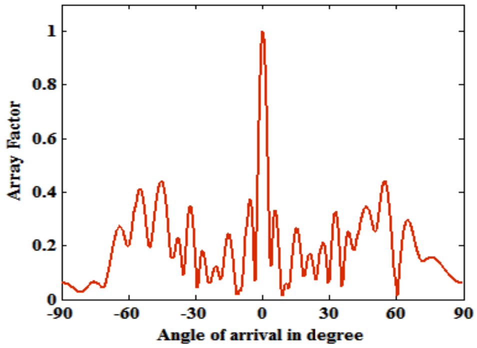

Fig 5. Optimized power pattern obtained using RLS

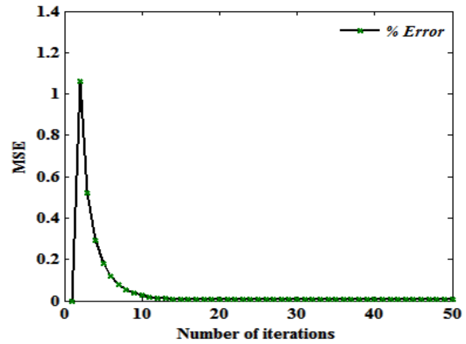

Fig 6. MSE pattern with desired AOA=0 deg. and interferer AOA=60 deg. obtained using RLS

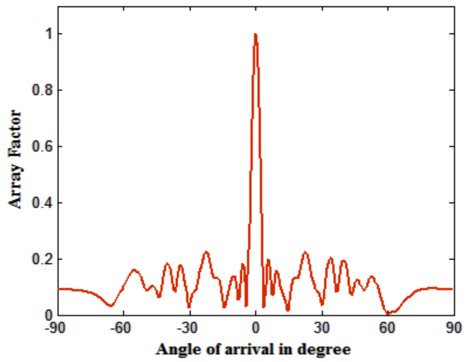

Fig 7. Optimized power pattern obtained using SMI

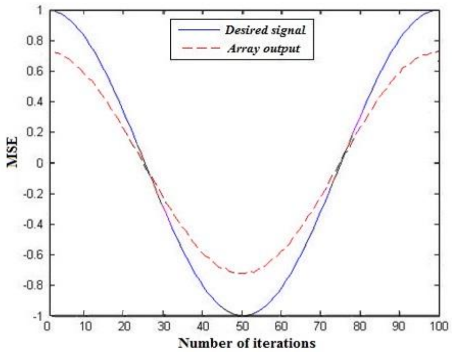

Fig 8. MSE pattern with desired AOA=0 deg. and interferer AOA=60 deg. obtained using SMI

spaced array obtained using LMS and the MSE pattern where the error variation between the desired signal and array output signal obtained using LMS algorithm. In case II, fig 5.,fig 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 case III, fig 7., fig 8. represents the optimized power pattern of uniformly spaced array obtained using SMI and the MSE pattern where the error variation between the desired signal and array output signal obtained using SMI algorithm. When the comparison between these three cases observed, the adaptive antenna assembly showed better performance in case II. As in case I, the convergence between the array output signal and desired signal is clearly observed after 40th number of iterations, also in case III, the convergence of array output signal and the desired signal is conventionally does not occurred, the array output signal intersect the desired signal after 30th and 70th number of iteration but doesn’t stayed for a long time. Whereas in case II, after 20th iteration the convergence between the array output and desired signal is clearly observed.

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CONCLUSION

In this article a smart or adaptive antenna array system is optimized using LMS, RLS and SMI. One of the drawbacks of LMS algorithm is it must go through many iterations before satisfactory convergence is achieved. One of the possible approaches to circumventing the relatively slow convergence of the LMS scheme is by use of SMI method. This method is alternatively called as DMI. Though SMI algorithm is faster than the LMS algorithm, the computational burden and potential singularities can cause problem. This problem is solved by recursively calculate the required correlation matrix correlation vector using RLS algorithm. In all this cases the reference signal is needed. Optimized patterns reveal that RLS algorithm involves more computations than the LMS and SMI algorithm; it also provides better response towards the co-channel interference, the rate of convergence RLS algorithm is faster than LMS & SMI algorithm, which is visible from the simulated results i.e. after 20th iteration the convergence between desired signal and array output is occurred which is much faster convergence rate than LMS and SMI algorithm, so the superiority of RLS algorithm is thus proved by the proposed approach. These algorithms have been simulated using MATLAB 7.0.1 (R14) version software in Windows 7 (32 bit) environment.

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