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Adaptive Beam forming of Smart Antenna using Conjugate Gradient Method

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ABSTRACT:

This Paper focused on adaptive conjugate gradient method (CGM) algorithm and the same is compared with one of the fastest adaptive algorithm named recursive least squares (RLS) algorithm. This algorithms has improved the computation complexity and better convergence. MATLAB simulation showed that conjugate gradient algorithm has better output signal resolution.

Key words: conjugate gradient method, recursive least squares

INTRODUCTION

A smart antenna usually involves spatial processing and adaptive filtering techniques. The field of application is very large, ranging from signal to noise improvement to the user capacity enlargement of the mobile network. A typical application will involve an adaptive algorithm to create a beam to track a user or to eliminate noise sources and therefore the smart antenna is also referred to as adaptive array or adaptive beam former. This chapter discusses two algorithms, the Least Mean Square algorithm and the Constant Modulus algorithm.

2.1. Smart antenna basics

The smart antenna is basically a set of receiving antennas in a certain topology.

The received signals are multiplied with a factor, adjusting phase and amplitude.

Summing up the weighted signals, results in the Output signal. The concept of a transmitting smart antenna is rather the same, by splitting up the signal between multiple antennas and then multiplying these signals with a factor, which adjusts the phase and amplitude. Figure 1 represents the concept of the smart antenna. The signals and weight factors are complex.

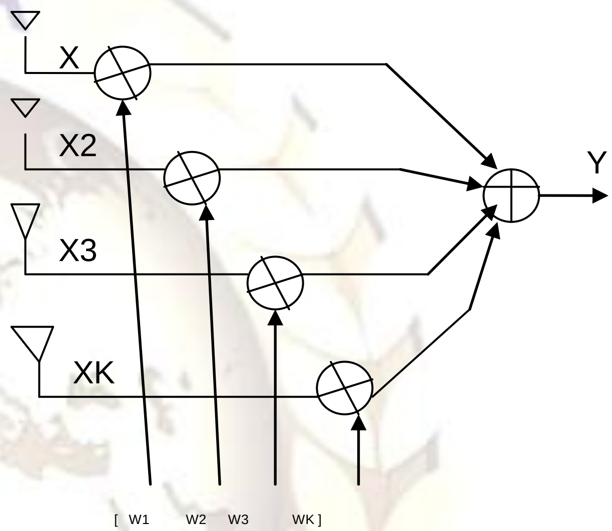


Figure 1, smart antenna concept for a receiving antenna

The following mathematical foundations on the smart antenna concept can be found in [5]. If the wave front arrives at the array antenna as shown in Figure 2, the wave front will be earlier on antenna element k+1 than element k. The difference in length between the paths is dsinθ. If the arriving signal is a harmonic signal or frequency, then the signal arriving at antenna k+1 is leading in phase compared with antenna k. The signal that arrives at antenna element zero is considered to have a phase lead of zero. The signal that arrives at antenna k, leads in phase with ξkdsinθ, where ξ=2π/λ and λ is the wavelength.

The weight vector is defined by:W=[w0,w1,w2,--wk-1]T ----------- (1)

Now the array factor is defined by:

$F=w^{T}v$ ----------------------- (2)

Where

$V=[1\ e^{j\xi d\sin\varphi} e^{2j\ \xi d\sin\varphi} --- e^{j(k-1)\ \xi d\sin\varphi}]$------(3)

Here

K=no. of antennas

W_k=weight vector of antenna k

V=Array propagation vector

2.2. Adaptive beam forming

Adaptive beam forming can be done in many ways. Many algorithms exist for many applications varying in complexity. Most of the algorithms are concerned with the maximization of the signal to noise ratio. A generic adaptive beam former is shown in Figure 3. The weight vector w is calculated using the statistics of signal x (t) arriving from the antenna array. An adaptive processor will minimize the error e between a desired signal d(t) and the array output y(t).

Some adaptive algorithms that suitable in mobile communication with their implementation issues then were briefly discussed. This includes LMS algorithm, SMI technique, RLS algorithm touching on the pro and cons of each of them. Other algorithms that proposed to overcome shortcomings or improve the performance of the three basic algorithms such as conjugate gradient method, eigenanlysis algorithm, rotational invariance **method**, linear least square error (LSSE) algorithm, and Hopfield neural network with respective references are listed.

The estimation technique of spatial reference signals referred as Angle of Arrival (AOA) of the desired signal was categorized into two groups. The first group named as wave number estimation is based on decomposition of a covariance matrix whose terms consist of estimates of the correlation between the signals at the elements of an array antenna.

Simplicity of Least Mean Square (LMS) algorithm makes it widely been used for tap coefficient adaptations of an adaptive processor in antenna array. However, this continuous adaptation approach algorithm causes signal acquisition and tracking problems due to its slow convergence in multipath fading channel. This is not suitable for mobile communication and some other measures need to be taken if this algorithm is to be used such as power control or normalized LMS algorithm. Converging faster than LMS algorithm, SMI has attracted to be applied in mobile communication. However, implementation difficulties need to be considered since its complexity requires advance hardware capability and the use of finite precision arithmetic may cause numerical instability. RLS can be seen as the solution for the slow convergence of LMS and high complexity of SMI. This is provided that SNR is high and setting of a fading rate dependent forgotten factor is correct [4]. Computer simulation results for mobile communication application shown that RLS outperform LMS and SMI in flat fading channels. Another algorithm, conjugate gradient method was studied to mitigate multipath fading effect in mobile communication and shown a better BER performance than RLS.

CONJUGATE GRADIENT METHOD

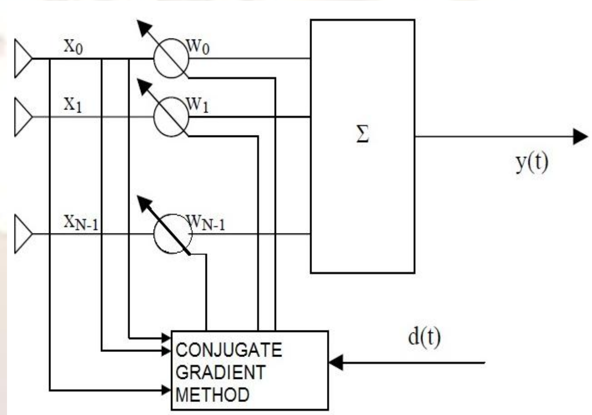
The Conjugate Gradient method is an effective method for symmetric positive definite systems. The method proceeds by generating vector sequences of iterates, residuals corresponding to the iterates, and search directions used in updating the iterates and residuals.

The unpreconditioned conjugate gradient method constructs the k^{th} iterate x^k as an element of $x^0 + span\{r^0, \ldots, A^{k-1}r^0\}$ so that $(x^k - \hat{x})^T A(x^k - \hat{x})$ is minimized, where $\hat{x}$ is the exact solution of Ax=b.

This minimum is guaranteed to exist in general only if A is symmetric positive definite. The conjugate gradient iterates converge to the solution of Ax=b in no more than n steps, where n is the size of the matrix.

In every iteration of the method, two inner products are performed in order to compute update scalars that are defined to make the sequences satisfy certain orthogonal conditions. On a symmetric positive definite linear system these conditions imply that the distance to the true solution is minimized in some norm.

The block diagram of conjugate gradient algorithm as shown below



The above diagram is the smart antenna concept for a receiving antenna. In this diagram, contains N-1 antennas and their corresponding weighted vectors are w1, w2, w3, ---, w(N-1).y is the summation of the all reference signal with vectors.

The covariance matrix of the input vector X for a finite sample size is defined as the maximum likelihood estimation of matrix R and can be calculate as

$R(N)=1/N*\sum X.X^H$------------------(4)

HereK=no. of antennas

X(t)=received signal from the antenna elements.

w^H=output of the beam form antenna.

$(.)^H$=Hermetian operator.

The optimum weight vector that correspond to the estimated matrix R_k for any i-th channel is given by

$W=R^{-1}V$----------------------------- (5)

Where

$V=[1\ e^{j\xi d\sin\varphi} e^{2j\ \xi d\sin\varphi}---e^{j(k-1)\ \xi d\sin\varphi}]$------(6)

Here K=no. of antennas

W=weight vector

V=Array propagation vector.

The iterates x^k are updated in each iteration by a multiple α^k of the search direction vector p^k:

$$x^k = x^{k-1} + \alpha^k p^k$$

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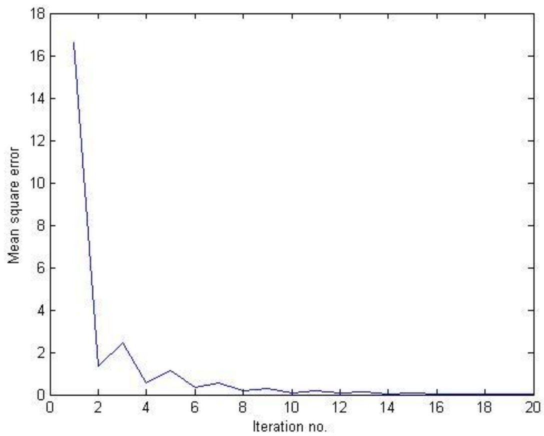
Correspondingly the residuals $r^k = b - Ax^k$ are updated as

$$r^k = r^{k-1} - \alpha A p^k$$

The choice $\alpha = r^{k-1^T} r^{k-1} / p^{k^T} A p^k$ minimizes $r^{k^T} A^{-1} r^k$ The search directions are updated using the residuals $p^k = r^k + \beta^{k-1} p^{k-1}$ where the choice $\beta^k = r^{k^T} r^k / r^{k-1^T} r^{k-1}$ ensures that r^k and r^{k-1} are orthogonal.

Fig 1.MSE OF CGM algorithm



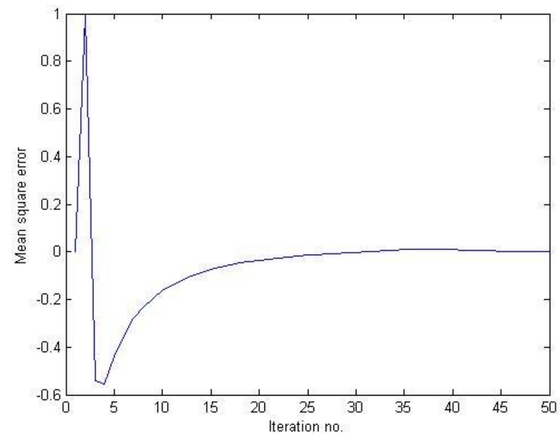
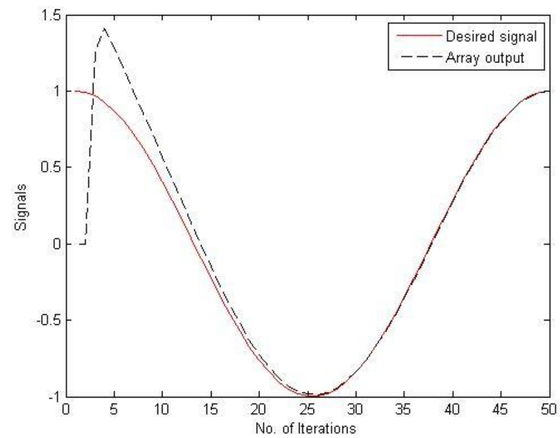


Fig 2.Mean Square Error0f RLS algorithm



.Fig 3. Array factor output OF CGM algorithm

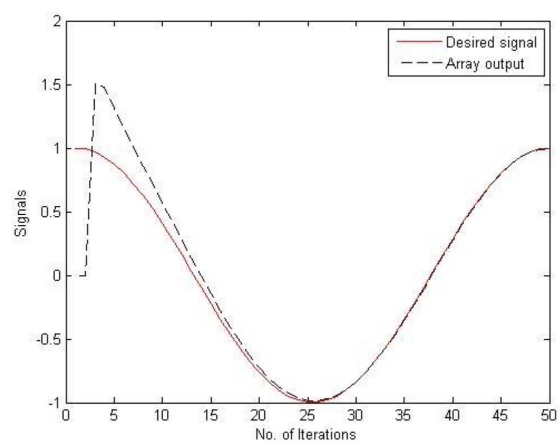


Fig 4. Array factor output 0fRLS algorithm

The fig 3 and fig 4 shows the main beam is oriented toward the desired signal (Φ=30o) and the nulls are pointed in the directions of the interfering signals (Φ=10o).

Conclusion:

The Conjugate gradient method provides good performance in a discontinuous traffic when the number of interferers and their positions remain constant during the duration of the block acquisition. The simulationresults show that the proposed method has better output signalresolution.The meansquare error (*MSE*) between the desired signal and thearray output signal at each iteration which converges toward zero after teniteration.

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