International Journal of Advanced Research in Electronics and Communication Engineering (IJARECE)
Volume 3, Issue 7, July 2014

Design and Performance Analysis of Adaptive Beamforming Algorithm for Smart Antenna Systems

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Abstract:
Beamforming is a technique in which an array of antennas is exploited to achieve maximum reception in a specified direction by estimating the signal arrival from a desired direction while signals of the same frequency from other directions are rejected. This is achieved by varying the weights of each of the sensors (antennas) used in the array. It basically uses the idea that, though the signals emanating from different transmitters occupy the same frequency channel, they still arrive from different directions. We designed and analyzed the performance of Least Mean Square algorithm for the smart antenna system. The proposed algorithm is simulated and analyzed using MATLAB. The results of LMS outputs are studied and compared with different array elements and for different element spacing. One of the simplest algorithms for adaptive processing is based on the Least Mean Square (LMS) error. Although the complexity of the algorithm is very low, its results are satisfying in many cases. The algorithm is very stable and it needs few computations, which is important for system implementation. The performance of LMS algorithm is also compared on the basis of normalized array factor and Mean Square Error (MSE) for Smart Antenna systems. It is observe that the array output acquires and tracks the desired signal after 20 iterations and involves less complexity in design and computation.

Key Words: LMS, Adaptive Beamforming, Smart antenna.

I. INTRODUCTION

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. Adaptive beamforming 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 beamformer is shown in Figure 1. 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)*. The computational power of many systems is limited and should be managed wisely.

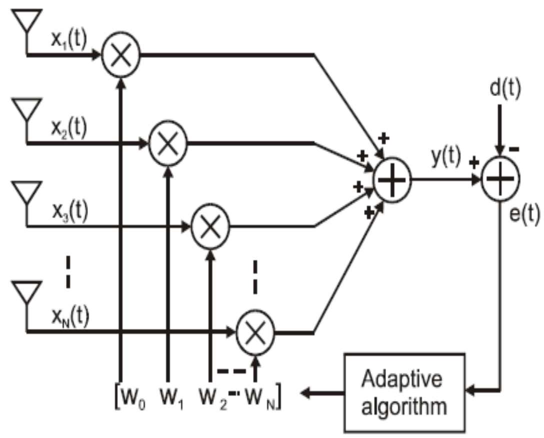

Fig. 1: Aadaptive beamforming configuration

II. LMS ALGORITHM

The Least Mean Square (LMS) algorithm uses a gradient based method of steepest decent. LMS 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. LMS algorithm is relatively simple; it does not require correlation function calculation nor does it require matrix inversions [1]. The LMS algorithm can be considered to be the most common adaptive algorithm for continues adaptation. It computes and updates the weight vector. Due to the steepest-descend the updated vector will propagate to the vector which causes the least mean square error (MSE) between the beamformer output and the reference signal [Gross 2005]. It is established quadratic performance surface. When the performance surface is a quadratic function of the array weights, the performance surface $J(\overline{w})$ is in the shape of an elliptic paraboloid having one minimum. We can establish the performance surface (cost function) by again finding the *Mean Square Error* (MSE) [1].
The squared error is given as

$$|\varepsilon(k)|^2 = \left|d(k) - \overline{w}^H(k)\overline{x}(k)\right|^2 \qquad (1)$$

Momentarily, we will suppress the time dependence. The cost function is given as

$$J(\overline{w}) = D - 2\overline{w}^H \overline{r} + \overline{w}^H R_{xx}\overline{w} \qquad (2)$$

Where: $D = E[|d|^2]$

ISSN: 2278 – 909X

To find the optimum weight vector $\overline{w}$ we can differentiate Eqn. (2) with respect to w and equating it to zero. This yields:

$$\overline{w}_{opt} = \overline{R}_{xx}^{-1}\overline{r} \tag{3}$$

Because we don't know signal statistics we must resort to estimating the array correlation matrix ($\overline{R}_{xx}$) and the signal correlation vector ($\overline{r}$) over a range of snapshots or for each instant in time. The instantaneous estimates are given as

$$\hat{R}_{xx}(k) \approx \overline{x}(k)\overline{x}^{H}(k) \tag{4}$$

and

$$\hat{r}(k) \approx d^{*}(k)\overline{x}(k) \tag{5}$$

We can employ an iterative technique called the method of *steepest descent* to approximate the gradient of the cost function. The method of steepest descent can be approximated in terms of the weights using the LMS method advocated by Widrow [Gross 2005]. The steepest descent iterative approximation is given as

$$\overline{w}(k+1) = \overline{w}(k) - \frac{1}{2}\mu\nabla_{\overline{w}}(J(\overline{w})) \tag{6}$$

where, μ is the step-size parameter and $\nabla_{\overline{w}}$ is the gradient of the performance surface. Substituting the instantaneous correlation approximations, we have the *Least Mean Square* (LMS) solution.

$$\overline{w}(k+1) = \overline{w}(k) + \mu e^{*}(k)\overline{x}(k) \tag{7}$$

where $e(k) = d(k) - \overline{w}^{H}(k)\overline{x}(k)$ = error signal

The convergence of the LMS algorithm is directly related to the *step-size parameter* μ. If the step-size is too small, the convergence is slow and we will have the *overdamped* case. If the convergence is slower than the changing angles of arrival, it is possible that the adaptive array cannot acquire the signal of interest fast enough to track the changing signal. If the step-size is too large, the LMS algorithm will overshoot the optimum weights of interest. This is called the *underdamped case*. If attempted convergence is too fast, the weights will oscillate about the optimum weights but will not accurately track the solution desired. It is therefore imperative to choose a step-size in a range that insures convergence. It can be shown that stability is insured provided that the following condition is met

$$0 \le \mu \le \frac{1}{\lambda_{\max}} \tag{8}$$

where $\lambda_{\max}$ is the largest eigenvalue of $\hat{R}_{xx}$.

Since the correlation matrix is positive definite, all eigenvalues are positive. If all the interfering signals are noise and there is only one signal of interest, we can approximate the condition as

$$0 \le \mu \le \frac{1}{2\ \text{trace}\left[R_{xx}\right]} \tag{9}$$

III. SIMULATION RESULT

The LMS algorithm is simulated using Matlab software. Uniform linear array with more than five hundred samples is taken for the simulation. Spacing between the array elements plays very important role in the beamforming techniques and it taken as 0.5 lambda. The angle of arrival (AOA) for the desired user is zero degrees. Figure 2 shows the graph of normalized array factor versus AOA in degrees for the array elements 6, 8 and 15 keeping the spacing'd' constant. It is observed that the array directivity increases with the number of elements. Meanwhile the sidelobe levels and the number of sidelobes increases as the number of elements increased. A comparison of the various results derived from figure 2 is presented in table 1.

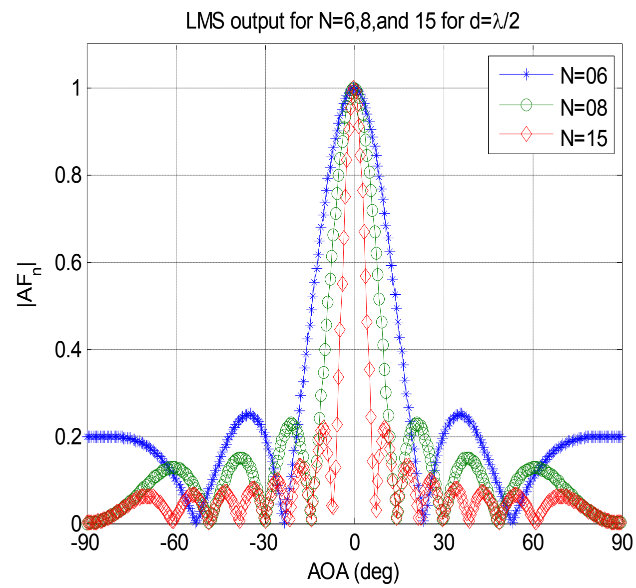

Fig. 2: Plot of normalized array factor versus AOA for different array elements.

TABLE 1

AOA in (Degrees)	Array Elements	Element Spacing	Step size µ	HPBW (Deg)	Beam Width (Deg)
0°	6	λ /2	0.01	23°	45°
0°	8	λ /2	0.01	20°	30°
0°	15	λ /2	0.01	13°	20°

Figure 3 shows the graph of normalized array factor versus AOA in degrees for the element spacing 0.5λ, 0. 25 λ and 0.125λ, keeping number of array elements constant. The

ISSN: 2278 – 909X

International Journal of Advanced Research in Electronics and Communication Engineering (IJARECE)
Volume 3, Issue 7, July 2014

spacing between the array elements is critical due to the side lobe problems, which causes the grating lobes. The grating lobes are the repetition of the main beams within the given range of angles. It is observed that the array directivity increases with the increase of spacing towards the lambda, but at the same time it can be noted that the array elements pattern suffers from the grating lobes. It can also be noted that the perfect result is obtained when the spacing is 0.5 lambda and result beyond the lambda is impractical and not suitable for the practical communication applications A comparison of the various results derived from figure 3 is presented in table 2. Figure 4 shows the plot of signals versus number of iterations. It is observe that the array output acquires and tracks the desired signal after 20 iterations. If the signal characteristics are rapidly changing, the LMS algorithm may not allow tracking of the desired signal in a satisfactory manner. The figure 4 shows relationship between the phase of desired signal and LMS output. It is observed that the phase of the desired signal and the phase of the LMS output is almost same. Figure 5 shows MSE error in each iteration. It is observed that MSE is decreases with each iteration and it is converge after 20 iterations.

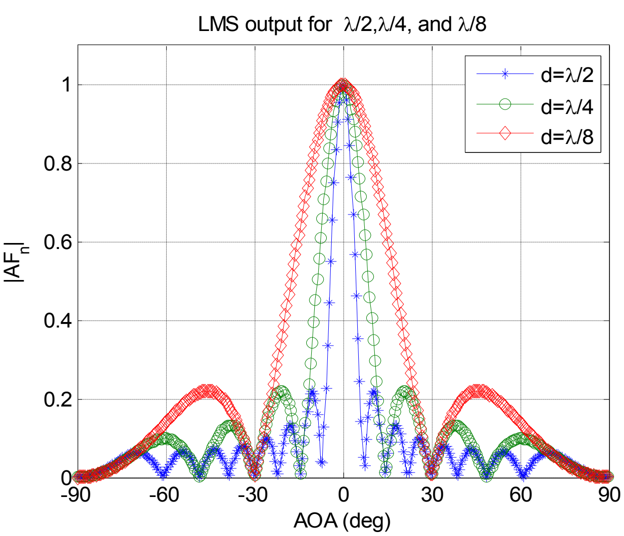

Fig. 3: Plot of normalized array factor versus AOA for different elements spacing.

TABLE 2

AOA in (Degrees)	Array Elements	Element Spacing	Step size μ	HPBW (Deg)	Beam Width (Deg)
0°	15	λ /2	0.01	23°	45°
0°	15	λ /4	0.01	20°	30°
0°	15	λ /8	0.01	13°	20°

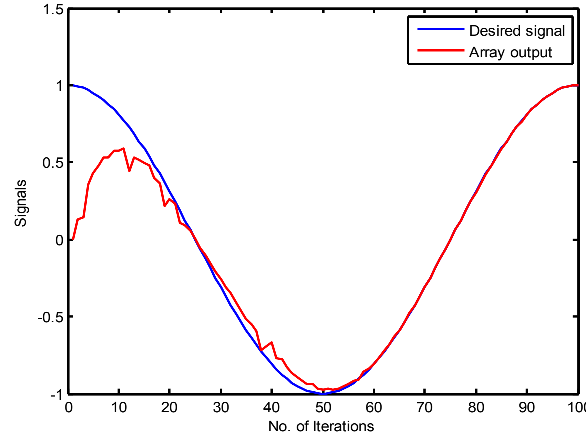

Fig. 4: Plot of Root mean square error versus number of iterations

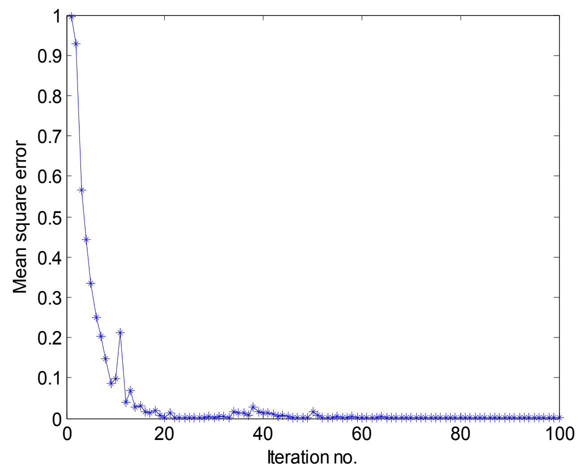

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Fig. 5: Plot of MSE Versus LMS output.

The figure 6 shows relationship between the magnitude of desired signal and LMS output. It is observed that the magnitude of the desired signal and the LMS output are almost same. Figure 7 shows the relationship between the Magnitude of desired signal and LMS output.

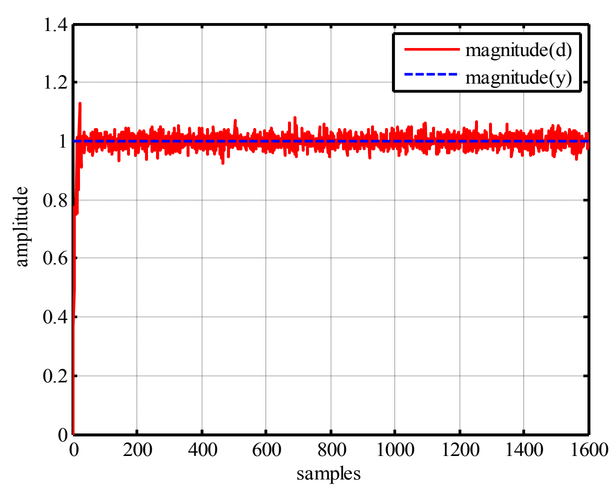

Fig. 7: Magnitude of desired signal and LMS output.

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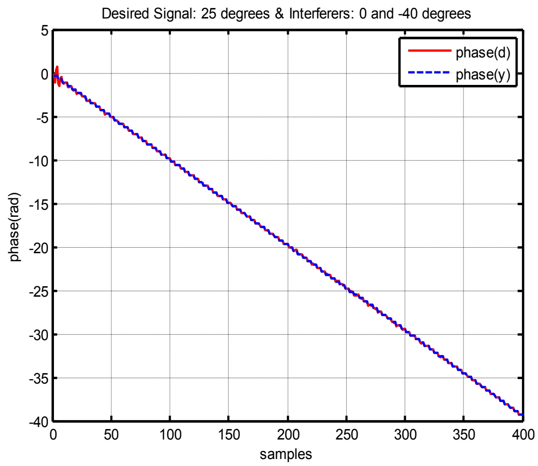

Fig. 6: Phase of desired signal and LMS output

Error between desired signal and LMS output is shown in figure 8.

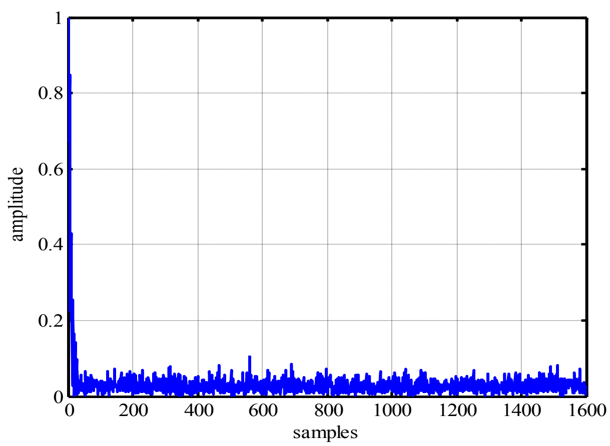

Fig. 8: Error between desired signal and LMS output.

The weights for the array elements N = 5 and element spacing half wavelength shown in table 3.

TABLE 3

S. No	Weights	Step size (μ)
1	w1 = 1-1.5144e-17i	0.0274
2	w2 = 0.84309-.027029i	0.0274
3	w3 = 0.7446+0.098082i	0.0274
4	w4 =0 .80772+0.24426i	0.0274
5	w5 = 0.96632+0.25837i	0.0274

IV. CONCLUSION

In this work, the proposed LMS algorithm was simulated using MATLAB. We analysis the performance of adaptive LMS algorithm for smart antenna systems for the different array elements and for different element spacing. It is clearly observed that the directivity of the radiation pattern increases with the increase in the array elements and wavelengths. On the other hand the grating lobes are more as the spacing between the antennas is increased. It is noted that in the LMS algorithm is highly sensitive to the step size. The approximate value of the step size taken for the simulation is about 0.01. Below and beyond this, we observe drastic change in the radiation pattern with respect to directivity and the beam width. The performance of LMS algorithm is compared on the basis of normalized array factor and mean square error (MSE) for SA systems and it is observed that the it converges after 20 iterations and it has less computational complexity compared to other adaptive beamfoming techniques.

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BIOGRAPHIES

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ISSN: 2278 – 909X