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Research paper

Cosine Least Mean Square Algorithm for Adaptive Beamforming

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Abstract

Beamforming and multiple-input multiple-output (MIMO) antenna configurations have received worldwide interest during the recent time. Various beamforming algorithm has been proposed and employed in different applications. The Least Mean Square (LMS) algorithm has become one of the most widespread adaptive beamforming techniques because of its simplicity and robustness. This paper presents a new variant of LMS algorithm named as Cosine Least Mean Square (Cos-LMS) which uses the efficient computation of array factor for linear antenna array.This algorithm gives improved performance in beam width reduction, side lobe level reduction, null depth, and stability as compared to standard LMS and other variants of LMS algorithm. The performance improvement by Cos-LMS algorithm is accomplished without increasing the computationalcomplexity of standard LMS algorithm.

Keywords:*Adaptive beamforming; Beam width; Cos-LMS; Side lobe level(SLL); Standard LMS*

1. Introduction

Adaptive beamforming and multiple-input multiple-output (MIMO) antenna configurations have received worldwide interest during the recent years. Beamforming has been used in diverse applications such as RADRAR, SONAR, communication, medical imaging, geology and astrophysics.Numerous adaptive beamforming algorithms have beenproposed and employed in different applications. Least Mean Square (LMS) developed by widrow [1] has been used in adaptive filter because of its simplicity and robustness [2]. The step size μ is the most critical parameter in LMS technique. Various techniques have been developed to optimize the step size. Some of which are normalized LMS, variable step size LMS [3]- [4], variable length LMS, transform domain [5] LMS. In recent times, modern optimization and adaptive techniques such as sequential quadratic programming, particle swarm optimization, chaotic and genetic algorithm [6]- [11] have been used for beamforming and antenna arrays radiation pattern synthesis.

The recent growth in telecommunication industry has triggered an enormous demand for better coverage, higher channel capacity and higher quality of service. Proposal of fast converging algorithms with reduced side-lobe levels (SLL) are indeed required to meet the demands of 4G and 5G networks for high speed data transfer [12]. This has been achieved by weighting, shading or windowing the array elements [13], [14]. However, designing antenna array with low SLL and narrow beam width is challenging [15]- [17]. The proposed algorithm not only converges faster than standard LMS algorithm but also achieves narrow beam width and reduced side lobe level. The proposed algorithm is a variant of standard LMS algorithm named as Cos-LMS.In this algorithm, the efficient computation of array factor using cosine function gives improved performance in side lobe level reduction, beam width reduction, null depth and stability.

The organization of this paper is as given: in Section2, system modeling of linear antenna array and Cos-LMS algorithm is presented. The simulation results are discussed in Section 3 and the conclusion is presented in Section 4.

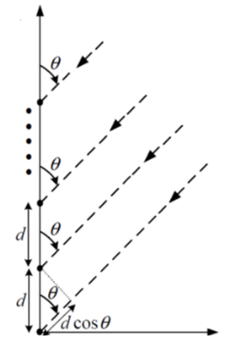


Fig. 1: Linear antenna array

2. System Model

Consider a system of *n* element uniform linear array, with inter spacing of the antenna elements is *d* as depicted in Fig. (1). Array factor for this system can be written as given in equation 1 [15]

$$\mathrm{AF}(\theta) = \sum_{0}^{n-1} \mathbf{w}(\mathbf{n}) e^{jnkd\cos(\theta)} \tag{1}$$

where k is the free space number, **w(n)**is array weight at element n and θ is the angle of incidence of incoming signal.
An adaptive beamforming system which requires reference signal is shown in Figure 2. The outputs of each antenna multiplied by weights are added together to produce the total output *y(n)* of the system. Weights are updated by some adaptive beamforming algorithm.

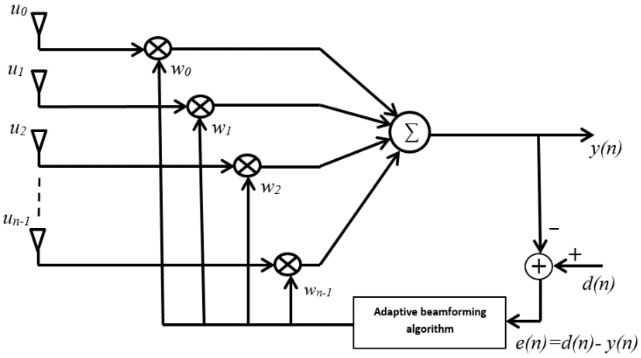


Fig. 2: Adaptive signal processing system

2.1. Cos-LMS Algorithm

In this work, a new algorithm, named as cosine least mean square (Cos-LMS) algorithm is presented. The major difference between standard LMS and Cos-LMS is the computation of array factor. The array factor in the proposed algorithm is computed by replacing the exponential function by a cosine function as given below

$$AF(\theta) = \sum_{0}^{n-1} \mathbf{w}(\mathbf{n}) \cos(kndcos(\theta)) \qquad (2)$$

This results in the reduction in side lobe level and width of the main beam. Weights are computed using the standard LMS algorithm. Consider a linear array model as depicted in figure 1. The antenna array receives signal form the desired source at an angle θ_0 and I signal from the undesired sources with the i^{th} interfering signal arriving at an angle θ_i. The Outputs of each antenna multiplied by weights are added together to produce the total output *y(n)* as depicted in figure 2 and given in equation (3).

$$y(n) = \mathbf{w}^H \mathbf{u}(n) \qquad (3)$$

where,

$$\mathbf{u}(n) = [\mathbf{u}_1(n)\ldots\ldots\mathbf{u}_N(n)] \qquad (4)$$

and

$$\mathbf{w} = [\mathbf{w}_1 \ldots \mathbf{w}_N] \quad e(n) = d(n) - y(n) \qquad (5)$$

u(n) represents the input vector and **w** represents weight vector.The weights are computed at every itineration according to equation 6

$$\mathbf{w}(n+1) = \mathbf{w}(n) + \mu \mathbf{u}(n) e^*(n) \qquad (6)$$

Where μ represents step size. The error signal is given by

$$e(n)=d(n)-y(n) \qquad (7)$$

Figure 3 shows the adaptive filter structure of the Cos-LMS algorithm. This Cos-LMS algorithm dynamically updated the array factor so that the main beam is oriented towards the desired signal and nulls are placed towards the interferers.

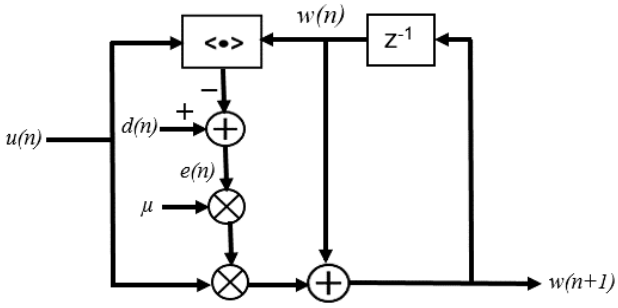
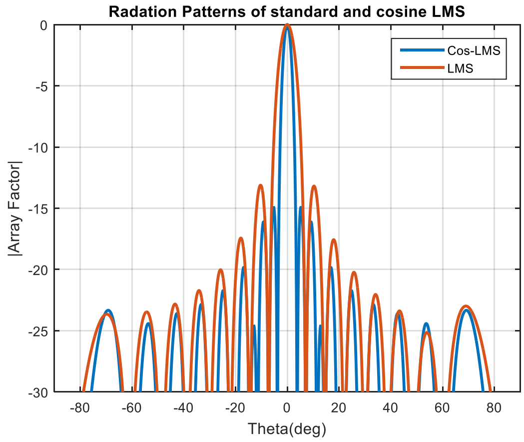
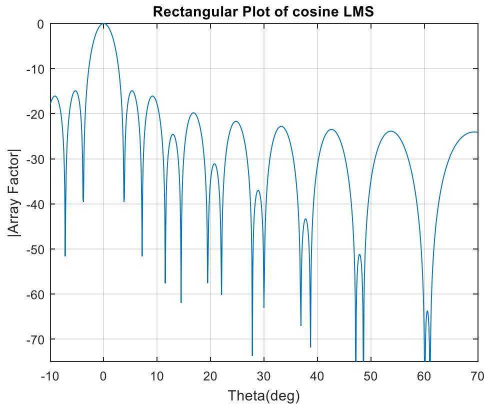


Fig. 3: Adaptive filter structure



(a) Radiation patterns of Cos-LMS and standard LMS

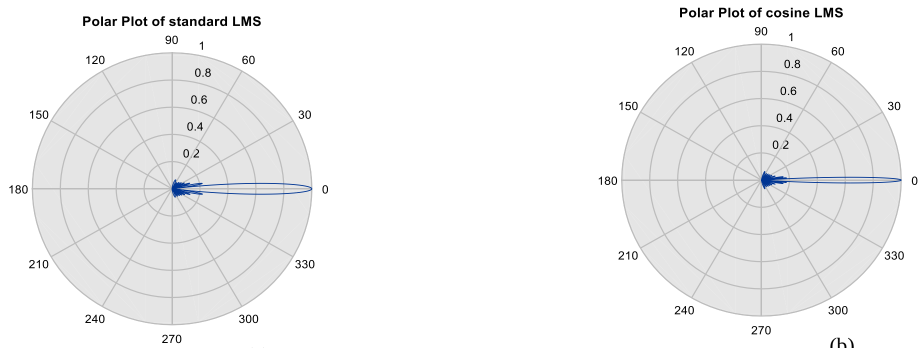


(b): Radiation patterns of Cos-LMS showing deeper null placement (below -75 dB) when interferer is at 60^0

Fig. 4

3. Simulation Results and Discussions

Several simulations have been performed in MATLAB for comparison of Cos-LMS with standard LMS algorithm, Normalized LMS (NLMS) and Sign LMS (S-LMS). The use of a cosine function to compute the array factor is shown to be more efficient than other approaches. First, A comparative analysis of standard LMS and Cos-LMS is performed and the results are depicted in figures 4,5 and 6.



(a) (b)

Fig. 5: Polar Plots of standard LMS and cos-LMS

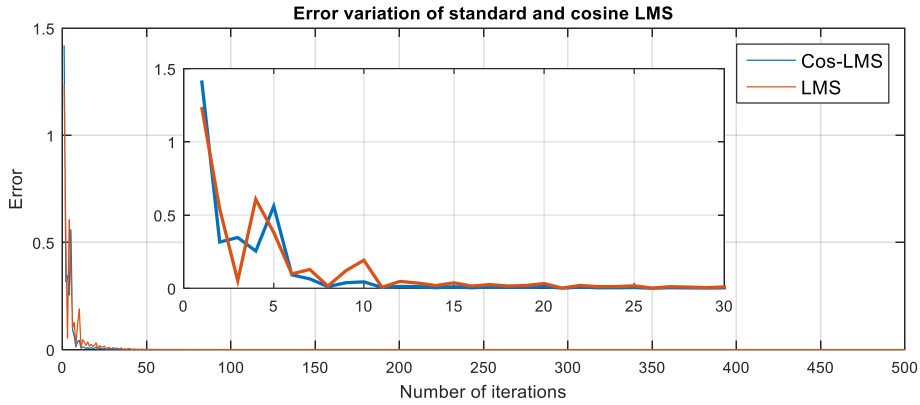
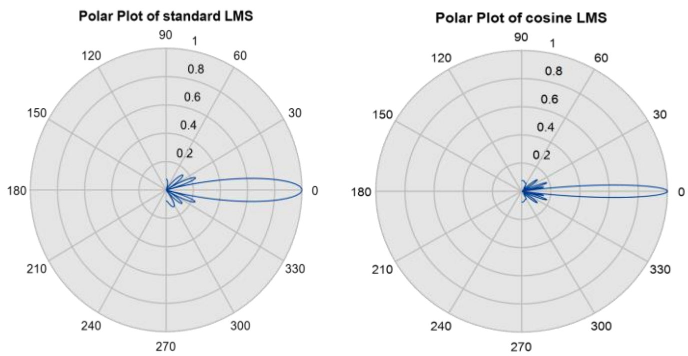


Fig. 6: Error variations of standard LMS and cos-LMS



(a) (b)

Fig. 7: Polar Plots of standard LMS and cos-LMS for 8 elements array

The desired and interferer signals are of sinusoidal type and gaussian noise is added. LMS and Cos-LMS algorithms are applied to 16 element linear array. The desired signal is at θ =0° and the interferer is at θ = 60°. An optimized value of step size μ=0.0163 is considered. To study the impact of noisy signal on the algorithm's performance, SNR is taken as 15 dB and signal to interferer ratio (SIR) is taken as. Figure 4 shows radiation patterns of standard LMS and Cos-LMS. It is evident that Cos-LMS gives better performance than standard LMS. Side lobe levels for Cos-LMS are reduced to -15 dB and the width of main lobe BWFN (beam width at first null) is also reduced to about half as compared with standard

LMS. This algorithm places deeper nulls up to -75 dB towards the directions of the interferers as depicted in figure 4b.

Figure 5 shows the polar plots of both Co-LMS and standard LMS. It is evident from figure 5 that Cos-LMS produces a narrower beam towards the desired signal and produces lower side lobe levels as compared to standard LMS.

Figure 6 depicts the error variation of standard LMS and Cos-LMS algorithm. Cos-LMS shows faster convergence and stability in comparison with standard LMS. The error value of Cos-LMS reduces rapidly and approaches to zero in few iterations.

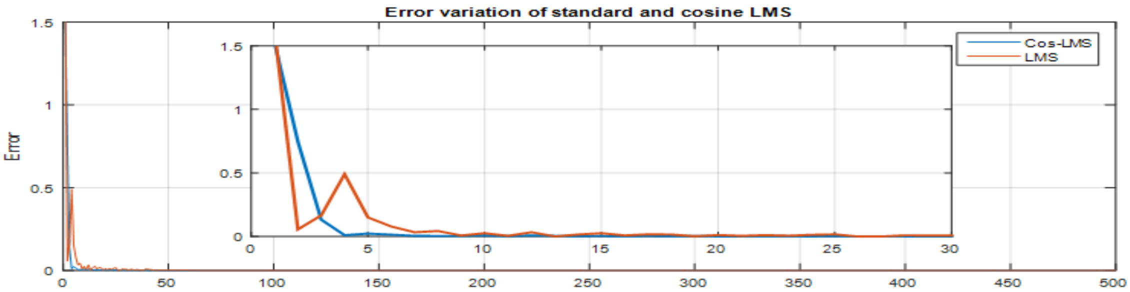


Fig. 8: Error variations of standard LMS and cos-LMS for SNR=3dB

3.1 The Influence of Varying Number of Antennas

To analyze the influence of varying the number of antenna elements on algorithm, simulation was carried with 8 elements array and results are depicted in figure 7. It is observed from figure 7 that Cos-LMS produces narrower beam towards the desired signal in comparison with standard LMS.

3.2 Impact of Noisy Signal on Cos-LMS Algorithm

To analyze the impact of reference signal with large noise on the performance of Cos-LMS algorithm, SNR is decreased to 3dB and results are shown in figure 8. As SNR decreases from 10dB to 3 dB, the Cos-LMS algorithm shows faster convergence and stability than standard LMS. Based on the simulation results in fig 8, it is concluded that Cos-LMS algorithm is very robust to the presence of noise in the reference signal. It accurately estimates the direction of desired signal and rejects the interference signal by placing deep nulls up to -75dB even in the presence of noise.

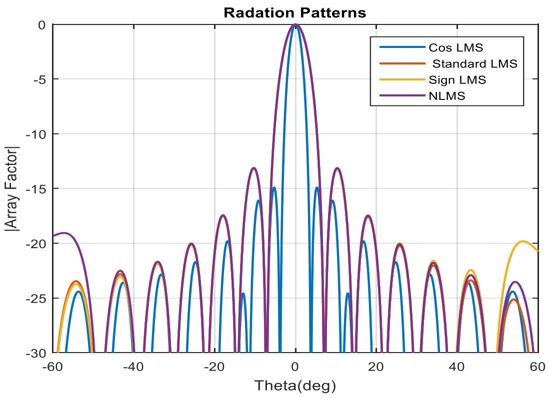


Fig 9: Radiation patterns of Cos-LMS,S-LMS, Standard LMS and N-LMS

3.3 Comparison of Cos-LMS with Other Variants of LMS

MATLAB simulation for comparison of Cos-LMS with standard LMS algorithm, Normalized LMS (NLMS) and Sign LMS (S-LMS) is executed and the results are depicted in figure 9. It is evident form figure 9 that Cos-LMS achieves reduced SLL and narrower beam width in comparison with standard LMS, NLM and S-LMS.

4. Conclusion

A new beamforming algorithm, called Cos-LMS has been presented. A comparative study of this algorithm with standard LMS and some variants of LMS is also presented. It can be concluded form the simulation results that the Cos-LMS gives better performance in beam width reduction, null depth, side lobe level reduction, precision and stability. Null placement of below -75 dB is achieved in this algorithm, this deeper null placement will make the algorithm suitable for interference rejection. Beam width at first null achieved in Cos-LMS is about half as compared to standard LMS.

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