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Improving the VSSNLMS adaptive beamformer for adaptive antenna systems

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***Abstract*---**A new configuration for the adaptive beamforming technology has been presented in this research work. We modified the structure of the uniform linear array (ULA) in such a way that a correct beam can be formed uniformly for all azimuth angles. For ULA composed of M antennas, we place two extra elements on the top and the bottom of the configuration of the ULA (at the array axis). Then, we develop the mathematical model or the same. To investigate the efficacy of the proposed antenna configuration, we deploy the VSSLMS beamformer. The new beamformer is compared with the well-known LMS and the MLMS adaptive beamformer. Computer simulations are provided in the result section of this paper to validate that the new beamformer has enhanced convergence rate and high data transmission compared to the LMS and the NLMS methods. Also, the new method has the same performance for middle angles, near boresight and array end fires which is not possible for the LMS and the NLMS method using a ULA.

***Keywords*---**adaptive beamforming, LMS, NLMS, VSSNLMS, ULA.

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Introduction

Adaptive beamforming technology has been extensively deployed in numerous applications including radar [1], satellite [2], sonar [3], seismology [4], astrophysics [5], etc. Among the numerous approaches, LMS [6]-[7], NLMS [8] and variable step-size LMS [9] are the most popular methods. These methods use the constant step size for beamforming and require more samples. In practice, for smart beamforming, the step size should be adaptive instead of constant. Also, in certain cases, only a few samples number is available at the receiver. In such cases, the performance of the LMS, NLMS, and SMI deteriorates. This problem can be circumvented by making the step size adaptive. For, the LMS and the NLMS methods, a lot of iterations are carried to minimize the error between the desired signal and the array output. Once the error becomes zero or minimum, the array output can be used for the next stage. Some beam-forming algorithms take many iterations, and some require less iteration to produce output.

In array signal processing, ULA is the most studied method due to its simplicity. This configuration provides high directivity narrow beams to represent the user direction. They provide one dimensional (1-D) (azimuth) coverage. Nonetheless, ULAs would not provide satisfactory results for all the directions [10]-[14]. They are best suited only near the bore sites and middle angles. ULA partially and in some cases completely fails to for beam near the array end fires. To have full coverage (360^o), uniform circular arrays (UCAs) could be considered [15]. They provide 2-D coverage which includes both elevation and azimuth directions. UCAs provide uniform accuracy for all angles. Nevertheless, the beams formed by this configuration have wider nature. Thus, the directivity and the resolution of the array are poor. Also, UCAs are complicated in implementation and analysis and does not suitable for most of the applications. In a few papers [16]-[19], multi-ring arrays which are also called concentric circular arrays (CCAs) were considered for the LMS implementation. Nevertheless, these arrays provide the required resolution at the cost of high computational complexity. Another type of configuration is the planar array (PA). This type of array configuration is not suitable for most wireless applications due to low accuracy, and it deviates in the noise environment.

Recently, displaced antenna arrays (DAAs) [20], L-shaped array, V-shaped array, hexagonal arrays have been proposed for smart antenna beamforming. However, all these types can provide the 2-D signal estimation and are applicable in specific applications. The LMS beamformer is the most used beamformer in many wireless applications including military surveillances and mobile communications due to its simplicity. This beamformer needs just $O(M)$ flops to compute the complex array weights. Here, M represents the antenna array size. Nevertheless, its application in a few systems is hindered due to very slow convergence speed. This beamformer needs more than 90 iterations before providing the main beam in the desired direction. The slow convergence affects the efficacy of the beamformer when a signal is changing rapidly. Thus, the LMS method is not suitable for current and future communication systems. The problem of slow convergence is circumvented to some extent in the NLMS algorithm [21]-[22]. The fast convergence is achieved in this technique by avoiding the decomposition of eigenvalues and eigenvectors. This beam former is not sensitive and not immune to interferences due to normalization. However, in [23], it has been shown that this method has certain implementation issues. A few issues are:

- Miss-adjustment noise.
- Variation in antenna array weights.

To overcome the downsides of the LMS and NLMS methods, recently VSSNLMS algorithm has been presented. In our work, we exploit the VSSNLMS algorithm for the new ULA and the computer results are compared with the popular LMS and the NLMS beamformers.

The proposed Array signal model for VSSNLMS

Figure 1 shows the configuration of the ULA which composed of M antenna elements with a $d \le \lambda/2$ as a inter element spacing to avoid mutual coupling and grating lobes in adaptive beam forming. We assume N uncorrelated narrow band signals ($M > N$) impinge the ULA from far fields from $\theta_0, \theta_1, \theta_2, \cdots, \theta_{N-1}$ directions.

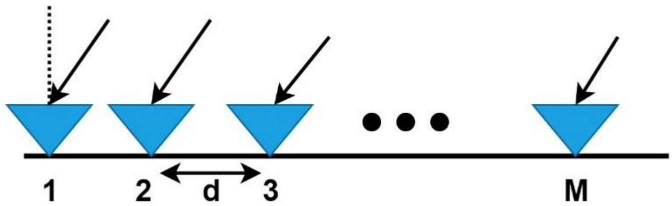

Figure 1. Classical ULA configuration

The signal received at the ULA is represented as

$$\mathbf{x}(n) = \sum_{n=0}^{N-1} s_n(n)\mathbf{a}(\theta_n) + \mathbf{n}(n) \qquad (1)$$

where $\mathbf{x}(n)$ is the M x 1 received vector.

$s_n(n)$ denotes the envelopes of the signal with n = 0, 1, 2,..., N-1.

$\mathbf{a}(\theta_n)$ is the M x 1 steering vector, which is responsible for steering the beam in the desired direction which is denoted as

$$\mathbf{a}(\theta) \cong \left[1, e^{-j2\pi d \sin\theta/\lambda}, \cdots, e^{-j2\pi d \sin\theta(M-1)/\lambda}\right]^T \qquad (2)$$

$\mathbf{n}(n)$ is the M x 1 white Gaussian noise with σ^2 variance and zero mean. Equation (1) denotes the vector form of the received signal. The vector and matrix form of (1) is

$$\mathbf{x}(n) = \mathbf{A}\, s_n(n) + \mathbf{n}(n) \qquad (3)$$

where $\mathbf{A}$ is the M x N manifold of steering vector known as Vondermonde matrix represented as

$$\mathbf{A} = [\mathbf{a}(\theta_1), \mathbf{a}(\theta_2), \cdots, \mathbf{a}(\theta_N)] \quad (4)$$

In our work, a modified ULA is represented by making of two extra antennas to the classical ULA at its axis as shown in Figure 2.

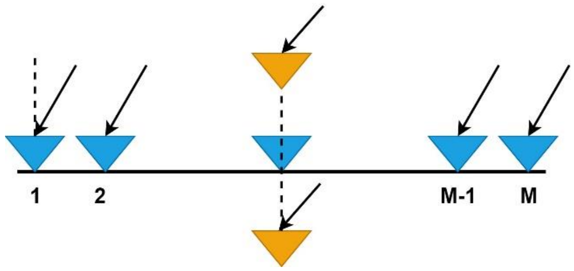

Figure 2. The proposed ULA configuration

The steering vector represented for the normal ULA in (2) is modified in as per the proposed ULA configuration and it can be denoted as

$$\mathbf{a}_{new}(\theta) \equiv \begin{bmatrix} \mathbf{a}(\theta) \\ e^{-j\left(\frac{M-1}{2}\right)k\,d\sin\theta} \cdot e^{jk\,d\cos\theta} \\ e^{-j\left(\frac{M-1}{2}\right)k\,d\sin\theta} \cdot e^{jk\,d\cos\theta} \end{bmatrix}^T \quad (5)$$

Now, the new Vondermonde matrix for the manifold of all steering vectors of (5) is

$$\hat{\mathbf{A}} = [\mathbf{a}_{new}(\theta_1), \mathbf{a}_{new}(\theta_2), \cdots, \mathbf{a}_{new}(\theta_N)] \quad (6)$$

The weights update equation of this algorithm is expressed as:

$$\mathbf{w}(n+1) = \mathbf{w}(n) + \left[\frac{\mu(n)}{\alpha_1 e(n)e(n)^* + (1-\alpha_1)e(n)e(n)^*}\right] \cdot e(n)^* \mathbf{x}(n) \quad (7)$$

Here

$$\mu(n) = \left\{\left(\frac{6}{M}\right)^2 \left(j\left(\frac{6}{M}\right)^2\right) + 0.001\right\} \quad (8)$$

Here: $\mu(n)$ is the step size and α_1 is the shaping parameter =0.1

In the above expressions, current and the updated array weights are respectively denoted by w (n) and w(n+1).

Let e(n) be the error that exists between the required and the array output. Let the required and the output of the array be d(n) and y(n) respectively.

$$e(n) = d(n) - y(n) \tag{9}$$

The output of the signal is given by

$$y(n) = \mathbf{w}(n)^H \cdot \mathbf{x}(n) \tag{10}$$

Finally, the array pattern is calculated as

$$\mathbf{p}(\theta) = \left|\mathbf{w}(n)^H \cdot \mathbf{a}_{new}(\theta)\right| \tag{11}$$

Results and Discussion

In this part, we demonstrate the computer simulations of the new method in terms of array factor patterns and mean square error (MSE) performances. The results of the proposed methods are compared with the popular LMS and the NLMS beamformers. In this first experiment, we consider the antenna array with 8 elements separated by 0.5λ. We assume that the signal with 10dB SNR is impinging the array from 20° and inferences are from (40° and 60°). The adaptive array pattern obtained is presented in Figure 3.

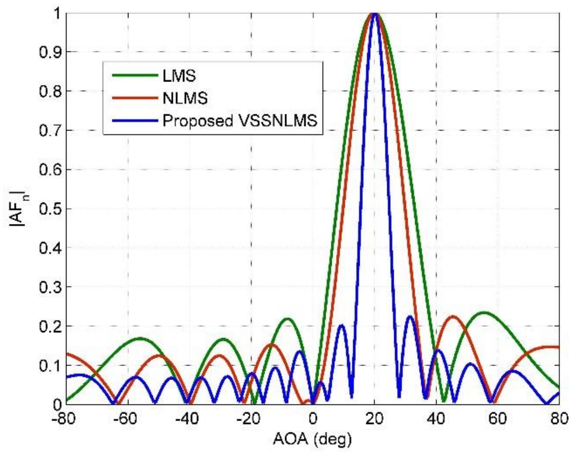

Figure 3. Array pattern for middle angles

In this result, we see that all three methods show the correct user direction. However, the beam widths of the LMS and the NLMS algorithms are quite large compared to the proposed method. This is due to the improvement in array calibration. Thus, the resolution of the proposed method using the new array configuration is high. In the second example, we analyze the efficacy of all beamformers for the MSE. Using the scenario of experiment 1, the MSE performances of all methods are demonstrated in Figure 4.

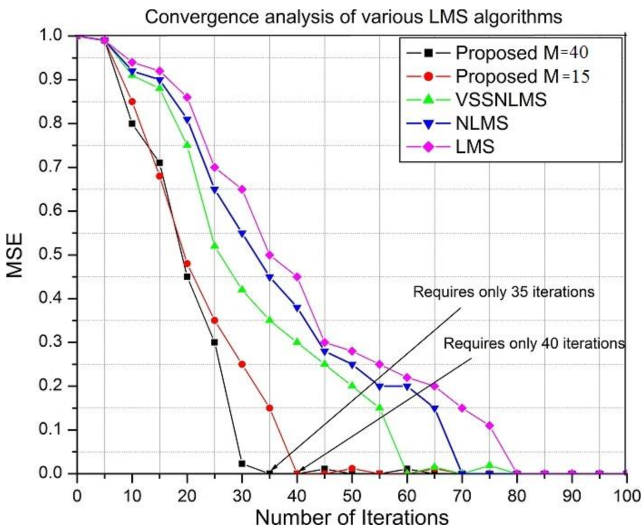

Figure 4. MSE versus iterations

In Figure 4, we see that the LMS beam former converges the MSE after about 80 iterations before producing the beam in the desired direction. The NLMS algorithm requires about 70 iterations and the proposed new method requires less that 35 iterations to converge. The reason for the improved convergence rate in the proposed method is mainly because of adaptive step size (ASS) with the modified weight updating equation. However, the LMS and the NLMS algorithms use the constant step size (CSS) which makes MSE converge to zero or minimum after many iterations. Hence, from Figure 4, we note that proposed method for M-15 and M=40 show the improvement of about 50% and 56.25% respectively over the LMS beamformer. Thus the convergence of the new beamformer is better than the LMS and the NLMS beamformers.

In the third experiment, we examine the efficacy of beamforming near the array end fires which fall in the range of $\left(-70^o \le \theta \le -90^o\right)$ and $\left(70^o \le \theta \le 90^o\right)$. We have seen in the first experiment that all three methods have provided the required angle of arrival estimation with good resolution at middle angles $\left(-60^o \le \theta \le 60^o\right)$ and at boresites. In this case, we consider the same situation of experiment 1 except that the signal is impinging the array at 78^o and -80^o. Computer simulations for a signal with AOA=78^o and -80^o are respectively demonstrated in Figures 5 and 6.

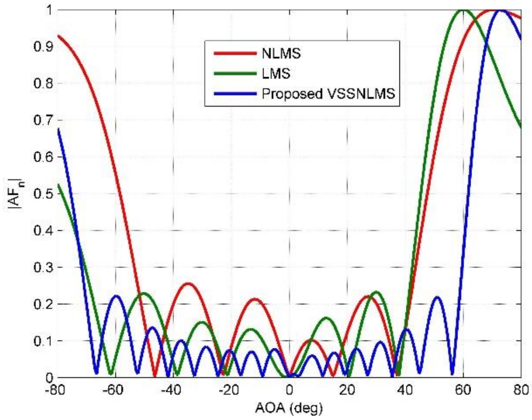

Figure 5. Beam forming for array endfire (AOA=78°)

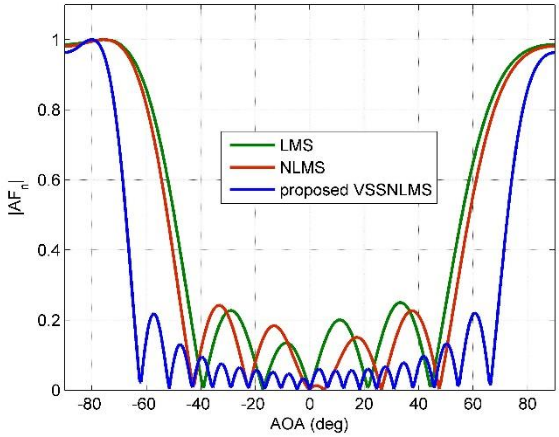

Figure 6. Beam forming for array endfire (AOA= -80°)

In Figure 5, we observe that the LMS and the NLMS algorithms make the incorrect AOA estimation with broader beam width. This is because the array patterns of these methods are drawn using classical ULA. Nevertheless, the modified array using the VSSLMS provided better results near the array end fires and makes the correct estimation. The same remarks can be drawn from Figure 6. Thus, this experiment shows that only the proposed method can form the beams near and at the array end fires for estimating the AOA of the user. The performances of the well-known beamforming methods and the proposed methods are summarized in Table 1.

Table 1
Performance analysis of proposed and well-known adaptive beamformers

Algorithm	Iterations required	Step size	Speed of algorithm	Beamforming near array endfires
LMS	80	Fixed	Slow	Poor
RLS	30	Fixed	Moderate	Poor

SMI	No Iterations (Block by block)	Not Applicable	Slow	Poor
CGM	20	Fixed	Fast	Poor
CMA	100	Fixed	Slow	Poor
NLMS	70	Fixed	Slow	Poor
VSSLMS	50	adaptive	Slow	Poor
proposed	35	adaptive	Moderate	Excellent

Conclusion

In this work, we devised an improved adaptive beamforming method for smart antenna systems by modifying a ULA configuration. The modified ULA by exploiting the VSSNLMS improves the efficacy of the beamforming, especially, adaptive array pattern is sharp and highly directive in the user direction. Also, the convergence speed of the new beamformer is superior to the LMS and the NLMS beamformers. Apart from these, the proposed method provides the uniform beamforming for the middle angles, near the bore sites, and at array end fires which is not possible for the LMS and the NLMS beamformers.

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