Beamforming in Smart Antenna using Some Variants of Least Mean Square Algorithm

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ABSTRACT
Beamforming and side lobe level reduction of smart antenna are important tasks in mobile network. Adaptive signal processing algorithms are used for beam forming in smart antenna. In this paper, variable step-size sign least mean square (VS-SLMS) algorithm is used for beam forming of smart antenna with linear antenna array. The results are compared with the results obtained using sign least mean square (SLMS) algorithm. Variable step-size algorithm shows good results for beam forming compared to ordinary constant step-size algorithm.

Keywords
Smart antenna, beam forming, side lobe level, linear array, variable step-size algorithm

1. INTRODUCTION
Smart antenna is used to enhance the performance of a mobile network. There are two types of smart antennas which are switched beam antenna and another is adaptive smart antenna [1-4]. In switched beam antenna, antenna can generate beam towards some predefined directions and in many cases, beam cannot be directed exactly towards the users. In adaptive smart antenna, based on the direction of arrival (DOA) estimation, using signal processing algorithm, beam can be generated towards the desired user and at the same time null of the antenna pattern can be generated [2,3] towards the interferer. The basic architecture of a smart antenna system with digital signal processing algorithm is shown in Figure 1. The Smart antenna system provides efficient spectrum utilization, enhanced security and low power consumption in mobile network [3, 4]. Various types of algorithms for beamforming, having their advantages and disadvantages, are available [1, 5-9]. A method of null steering and multi-user beamforming using phase control is described in [5]. Mostly used signal processing algorithms for adaptive beamforming are least mean square (LMS) and its variants, recursive least square (RLS) algorithm, sample matrix inversion (SMI) algorithm [6-8]. A hybrid beamforming algorithm is used in [9].

Variable step-size algorithms are based on non-constant values of convergence parameters and mainly applied to filter design [10-15]. A new LMS type algorithm is used to reduce the trade-off between mis-adjustment and tracking ability of the fixed step size LMS algorithm [11]. Very few reports are available [16] on the application of variable step-size signal processing algorithms to adaptive smart antennas.

In this paper, a comparative analysis is presented for adaptive beamforming of smart antenna using variable step-size signal processing algorithms. SLMS and VS-SLMS algorithms are used which are variants of LMS algorithm. Uniform linear array of 16 elements and 20 elements are considered with different inter-element spacing. Performance of variable step-size algorithm VS-SLMS is compared with the performance of adaptive beamforming obtained using SLMS.

2. VARIABLE STEP SIZE ALGORITHMS
LMS algorithm is an adaptive algorithm which incorporates an iterative procedure that makes successive corrections to the weight vector to obtain minimum error. Adaptive algorithm is used to minimize the error \( e(n) \) between desired signal \( d(n) \) and array output \( y(n) \), as [9]

\[
e(n) = d(n) - y(n)
\]

The weight updating equation for LMS algorithm is

\[
w(n+1) = w(n) + \mu e(n)x^*(n)
\]

Where, \( \mu \) is the step size parameter and \( e(n) \) is the error between output, \( e^*(n) \) is the complex conjugate of \( e(n) \) and the desired signal and \( x(n) = [x_1(n), x_2(n), \ldots, x_N(n)] \) is the signal received by the multiple antenna elements.

The weight updating SLMS algorithm equation is

\[
w(n+1) = w(n) + \mu e^*(n) sgn[x(n)]
\]

Where \( sgn[x(n)] = 1; \quad \text{for } x(n) > 0 \)
\[= 0; \quad \text{for } x(n) = 0 \]
\[= -1; \quad \text{for } x(n) < 0 \]

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Fig 1: Smart antenna system

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In variable step-size algorithms, step size parameter $\mu$ is not a constant. During weight updating, step-size parameter varies according to the formula [16]

$$\mu_{n+1} = \alpha \mu_n + \delta \epsilon_n , \text{ if } 0 < \mu_{n+1} < \mu_{\text{max}}$$

$$= \mu_{\text{max}}, \text{ otherwise}$$  (5)

where, maximum value of convergence parameter, $\mu_{\text{max}}$ is defined as $\mu_{\text{max}} = 2/\lambda_{\text{max}}$, and $\lambda_{\text{max}}$ is the largest eigenvalue of the correlation matrix of the signal. In Eq. (5), ‘$\alpha$’ and ‘$\delta$’ are constant parameters and in this paper, in simulation, the values chosen for these are $\alpha = 0.95$ and $\delta = 0.0003$. The factor $\epsilon_n$ in Eq. (5) is related to the weight vectors as

$$\epsilon_n = \|w(n+1) - w(n)\|/\|w(n+1)\|$$  (6)

Sign least mean square (SLMS) is used for faster adaptation process. In variable step-size sign least mean square (VS-SLMS) algorithm, the step size $\mu$ is also variable by following the above Eq. (3)

The weight updating VS-SLMS algorithm equation is

$$w(n+1) = w(n) + \mu_{n+1} \epsilon^*(n)x(n)$$  (7)

3. BEAMFORMING OF SMART ANTENNA USING LINEAR ANTENNA ARRAY

A uniform linear array of isotropic antennas is shown in Figure 2 where inter-element spacing between the antennas is ‘$d$’. For main beam at an angle $\theta$, array factor is expressed as [9]

$$AF = \sum_{n=1}^{N} A_n e^{j(n-1)(\beta d \sin \theta + \alpha)}$$  (8)

where, ‘$N$’ is the total number of antenna elements and phase factor $\beta = 2\pi/\lambda$. To generate main beam toward the desired beam direction $\theta$ from the broadside direction, the required progressive phase shift is

$$\alpha = -\beta d \sin \theta$$  (9)

![Fig 2: Linear antenna array](image)

The cost function is the normalized array factor which is a ratio of array factor (AF) to maximum value of array factor. In adaptive beamforming using variable step-size algorithms, first the parameters are initialized and then the adaptive signal processing algorithm is used. Then array factor is calculated and number of times iterated by updating weight to achieve the desired result related to beam direction, null direction and side lobe level.

Adaptive beamforming using VS-SLMS and SLMS algorithms for a linear array of 16 elements with inter-element spacing of 0.6$\lambda$, are shown in Figure 3. Desired beam and null directions are 20$^\circ$ and 25$^\circ$ respectively.

![Fig 3: Beamforming using VS-SLMS and SLMS for N=16, d=0.6$\lambda$.](image)

The results for adaptive beamforming are summarized in Table 1. For N=20, side lobe level is reduced by 2.1 dB using VS-SLMS compared to SLMS algorithm and for N=16, side lobe level is reduced by 1.7 dB using VS-SLMS algorithm.

![Fig 4: Beamforming using VS-SLMS and SLMS for N=20, d=0.5$\lambda$.](image)

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Algorithms</th>
<th>Beam obtained at</th>
<th>Null obtained at</th>
<th>SLL$_{\text{max}}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>N=16, d=0.6$\lambda$, desired beam at 20$^\circ$, null at 25$^\circ$</td>
<td>VS-SLMS</td>
<td>19.4$^\circ$</td>
<td>25.1$^\circ$</td>
<td>-7.8 dB</td>
</tr>
<tr>
<td></td>
<td>SLMS</td>
<td>19.4$^\circ$</td>
<td>25$^\circ$</td>
<td>-6.1 dB</td>
</tr>
</tbody>
</table>

![Table 1: Comparison of results using VS-SLMS and SLMS algorithms](image)
N=20, d=0.5λ, desired beam at 10°, null at 15°.

<table>
<thead>
<tr>
<th></th>
<th>VS-SLMS</th>
<th>SLMS</th>
</tr>
</thead>
<tbody>
<tr>
<td>angle</td>
<td>9.8°</td>
<td>9.6°</td>
</tr>
<tr>
<td>angle</td>
<td>14.9°</td>
<td>14.9°</td>
</tr>
<tr>
<td>MSE</td>
<td>-7.7 dB</td>
<td>-5.6 dB</td>
</tr>
</tbody>
</table>

The variation of step-size parameter (µ) with number of iteration in VS-SLMS is shown in Figure 5 for N=20, d=0.5λ at beam angle 10° and null angle 15°.

<table>
<thead>
<tr>
<th>iteration</th>
<th>step-size parameter (µ)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0.012</td>
</tr>
<tr>
<td>100</td>
<td>0.011</td>
</tr>
<tr>
<td>200</td>
<td>0.010</td>
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<tr>
<td>300</td>
<td>0.009</td>
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<td>400</td>
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<td>500</td>
<td>0.007</td>
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<tr>
<td>600</td>
<td>0.006</td>
</tr>
<tr>
<td>700</td>
<td>0.005</td>
</tr>
<tr>
<td>800</td>
<td>0.004</td>
</tr>
<tr>
<td>900</td>
<td>0.003</td>
</tr>
<tr>
<td>1000</td>
<td>0.002</td>
</tr>
</tbody>
</table>

![Fig 5: Variation of step-size parameter in VS-SLMS for N=20, d=0.5λ.](image)

Variation of updated weight with number of iteration in VS-SLMS is shown in Figure 6 for N=16, d=0.6λ at beam angle 20° and null angle 25°.

<table>
<thead>
<tr>
<th>iteration</th>
<th>weight (µ)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0.06</td>
</tr>
<tr>
<td>100</td>
<td>0.05</td>
</tr>
<tr>
<td>200</td>
<td>0.04</td>
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<tr>
<td>300</td>
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<tr>
<td>400</td>
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<td>800</td>
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<tr>
<td>900</td>
<td>0.00</td>
</tr>
<tr>
<td>1000</td>
<td>0.00</td>
</tr>
</tbody>
</table>

![Fig 6: Variation of Weight parameter in VS-SLMS for N=16, d=0.6λ.](image)

Mean square error in VS-SLMS for N=20, d=0.5λ at beam angle 10° and null angle 15° is shown in Figure 7.

![Fig 7: Mean square error in VS-SLMS for N=20, d=0.5λ.](image)

4. CONCLUSION

Comparative results of adaptive beamforming in smart antenna using variable step-size sign least mean square (VS-SLMS) algorithm and sign least mean square (SLMS) algorithm are presented here. After a large number of run for each and every case, the best results are presented here. Using VS-SLMS algorithms, faster convergence is achieved than SLMS. For interference reduction lower side lobe level is required and simulation results show that using VS-SLMS algorithm lower side lobe level can be achieved. Using VS-SLMS maximum side lobe level of 2.1 dB lower than that in SLMS algorithm is achieved. In all the cases, number of iteration is 1000.

5. REFERENCES


