Optimization of Normalized Least Mean Square Algorithm of Smart Antenna Beamforming for Interference Mitigation

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Abstract. A smart antenna is an array of antennas with signal processing capabilities to transmit/receive information in an adaptive manner. This capability continues to be investigated to find the best adaptive algorithm for the desired beamforming capability. This paper aims to provide a study and analysis of the effect of the normalized least mean square (NLMS) algorithm on step size parameter settings which have an impact on the desired minimum square error (MSE) value and on the nulling beam radiation pattern arrangement of smart antennas in its role in mitigating interference. The simulation for beamformer performance for 1000 iterations was carried out using the Matlab tool on the additional white noise gaussian (AWGN) channel and the simulation parameters were changed to some step size values (μ) with the NLMS algorithm for 16 antenna elements. The effect of the value of the step size μ is seen in the iterations number that takes place before the minimum error noise is obtained, where the increase in the value of this step size reduces the iterations number required; at the same time further improving MSE levels. From the pattern of amplitude response after the beamforming process, the result is an escalation in the number of nulling to increase the distance between the spaced elements taken. The interference source is eliminated/closed by placing the nulls in the path of the interference source where the worst interference level is obtained around -90 dB when the smallest step size is taken.

1. Introduction
An intelligent antenna consists of an array of two or N equally spaced antennas, working together to achieve a specific radiation pattern. This radiation pattern will determine the alignment and gain of the resulting antenna while the material for example can be made of microstrips with patch shapes in various options. Antenna elements work in a group of arrays that are generated either hardware or software. The system of smart antenna has the ability to change the radiation pattern to react to environmental changes so as to increase the capacity and S / N of the wireless system. Another advantage of smart antennas is the multipath effect is countered suppression of unwanted users and maximization of the beam to the desired angle. The system of the smart antenna is able to discern the signal you want and the neighboring interference channels normally. This system requires not only knowledge of the reference signal but also the path of the signal source you want. To put it another way, the system of smart antenna also requires training to update the existing weight values. [1] [2] The purpose of this research is to conduct an adaptive step size beamforming update study on the system of the smart antenna using the normalized least mean square algorithm, simulate the formation of a radiation pattern beam for several elements of a linear antenna array, and simulate the effect of the...
step size on changes in the value of minimum square error where MSE might be used to support analyze all its impacts in the process of eliminating unwanted signals in the form of interference or noise.

2. Smart Antenna Beamforming
As a preliminary illustration, the following Fig.1 shows a smart antenna beam pattern adjustment technique.

![Figure 1. Beamforming of smart antenna systems.[3]](image)

Although Smart Antenna systems are sometimes named space division multiple access (SDMA), SDMA is not a smart antenna. In SDMA, the antenna functions only to transform electrical signals to electromagnetic waves or vice versa, nothing else. Some of the adaptive algorithms used in signal processing have a significant effect on the presentation of the system of the smart antenna. The task of the algorithm in the smart antenna system is to adjust the received direction signal so as to the desired signal is the result of a combination. Several methods are implemented as adaptive algorithms. [4]

In comparison, humans can even hear sounds that are weaker than interference. The adaptive algorithms in the system of smart antenna do something similar to the brain’s abilities in this analogy, albeit sub-brained sophistication of course. Our brains could give the above signal selection and adaptive algorithm interference suppression with just two ears but multiple antennas are needed so that sufficient information on the user signal can be obtained. In humans, some people are smarter than others. For them to be smarter, they must have more developed brains. Likewise, some algorithms are smarter than others. Typically a smart algorithm takes more resources than a less intelligent algorithm. Unlike our brains which are free resources, many of the resources in the technological world are always more expensive and more complete components. [4]

2.1. Adaptive beamforming
The beam in the beam pattern of the array of the antenna can be arranged (beamforming) according to the design. Meanwhile, the adaptive algorithm is an algorithm that provides intelligence for the system of the smart antenna. The original signal is able to no longer be retrieved without an adaptive algorithm. In the beamforming approach with a fixed weight, the level of the angle of incidence does not conversion with time, so the optimum weight does not need to be adjusted. However, if the desired angle of incidence changes with time, it is necessary to design an optimization scheme that operates on-the-fly so that the optimum array weights are recalculated using the beamforming algorithm. [4]
Beamforming applies signal processing techniques to test the route (directionality) of the received signal or signal transmission in the antenna transducer array. Beamforming generates the antenna array radiation pattern by adding a signal phase in the wanted direction and by processing the nulling pattern for the undesirable direction. The phase and amplitude are suitable for maximizing the expected signal. A performance appraisal norm of a beamformer with the input data vector \( x(k) \) is the response of the antenna element weight vector \( w(k) \) as a function of the beam response. [4] [5]

![Diagram of adaptive beamforming](image)

**Figure 2.** K-elements of adaptive beamforming. [6]

Strong adaptive beamforming was a concern of intensive research for decades because, on the one hand, the importance of wireless communication, radar, sonar, microphones, radioastronomy, medical imaging, and other fields; and in comparison, because of the challenges associated with practical applications with strict reliability requirements. The presence of the wanted signal component in the training data, limited sample size, and inaccurate knowledge of the desired signal driving vector are the main causes of declining performance in adaptive beamforming. Traditional adaptive beamforming approaches do not have sufficient robustness and are not applicable in such situations, so produce the development of a number of robust adaptive beamforming techniques. Some examples of robust conventional adaptive beamforming methods are diagonal loading techniques, projection beamforming techniques, and eigenspace based beamforming. [7] [8]

### 2.2. Normalized Least Mean Square algorithm

A Uniform Linear Array (ULA) antenna array with \( N \) elements of isotropic, which is an integral portion of the system of adaptive beamforming is shown in Fig. 3. The antenna array output \( x(t) \) is given by [9]

\[
x(t) = s(t)a(\theta_0) + \sum_{i=1}^{N_x} u_i(t)a(\theta_i) + n(t)
\] (1)
As shown below, the output of each sensor is linearly combined after being multiplied by a certain weight value of the antenna array pattern. This optimization process is to obtain the maximum possible gain in the desired signal direction and nullify the gain (nulls gain) in the direction of the interference source.

\[ w(n+1) = w(n) + \mu \frac{1}{2} \mu [- \nabla E[e^2(n)]] \]

The main problem with the method of steepest descent is the calculation to find the realtime matrix values of \( r \) and \( R \). Meanwhile, the LMS algorithm simplifies the calculation by additionally using the instant values \( r \) and \( R \) to the actual values of \( r \) and \( R \). This instant value is \( S(t) \) for the desired signal arriving at angle \( \theta_0 \) and \( u(t) \) for the interference signal arriving at angle \( \theta_i \). The values \( a(\theta_0) \) and \( a(\theta_i) \) represent the steering vector for the wanted signal and the interference signal, respectively. The above parameters are needed to produce the desired total signal from the receiving signal which contains \( n(t) \) additional interference and noise.

\[ R(n) = x(n)x^h(n) \]
\[ r(n) = d * (n)x(n) \]

The weight update value from the following equation can be given then:

\[ w(n+1) = w(n) + \mu a(n)[d^*(n) - x^h(n)w(n)] = w(n) + \mu a(n)e^*(n) \]
The algorithm of LMS is opened with the free value \( w(0) \) for the weight vector at \( n = 0 \). The sequential correction of the weight vector then immediately goes to the smallest value of the mean squared error. The algorithm of LMS is then summarized into:

\[
\text{Output, } y(n) = w^H x(n) \tag{8}
\]
\[
\text{Error, } e(n) = d^*(n) - y(n) \tag{9}
\]
\[
\text{Weight, } w(n + 1) = w(n) - \mu x(n)e^*(n) \tag{10}
\]

In Normalized LMS (NLMS), the gradient step factor \( \mu \) is normalized by the vitality of the data vector:

\[
\mu_{NLMS} = \frac{\alpha}{x_k^H x_k + \sigma} \tag{11}
\]

where \( \alpha \) is usually \( 1/2 \) and \( \sigma \) is a very small number introduced to prevent division by zero if \( x_k^H x_k \) is very small.

\[
W_{k+1} = W_k + \frac{1}{x_k^H x_k} e_k x_k \tag{12}
\]

The normalization has several interpretations:

a. corresponds to the 2nd-order convergence bound
b. makes the algorithm independent of signal scalings
c. adjusts \( W_{k+1} \) to give zero error with current input: \( W_{k+1} x_k = d_k \)
d. minimizes mean effort at time \( k + 1 \)

NLMS usually converges much more quickly than LMS at very little extra cost; NLMS is very commonly used. In some applications, normalization is so universal that we use the LMS algorithm implies normalization as well.[10] If you consider the computation costs of LMS and NLMS on the same parameter, it is found that the multiplication number for LMS is \( 2N + 1 \) and for NLMS is \( 3N + 1 \), so in this case, NLMS is expensive in calculations. NLMS performs much better than LMS for non-stationary signals whose frequency varies with time. Performance can be accessed from a variety of parameters. The estimated output at the NLMS is nearby to the wanted signal compared to the LMS when we evaluate the error plot. If we consider stability, it is recognized that NLMS is very stable because LMS becomes unstable at higher step sizes. NLMS escape instability due to its normalized nature. The amount of variation in non-stationary signals is difficult to control. LMS performs relatively poorly for non-stationary conditions compared to NLMS. Instead, NLMS allows stable performance for non-stationary signals. The convergence slow rate of the NLMS can be controlled by increasing the step size by a limited number. Given the good level of stability and performance, it can be said that NLMS is much better than LMS for non-stationary signals. [11]

3. Method

In this study, the Matlab tool will simulate and display a beamformer performance. The channel of propagation taken is an additional Gaussian channel of white noise. The parameter is changed to compare some step size values in the NLMS algorithm for the number of array elements of 16. And for changes in the weight of the adaptive algorithm system, 1000 iteration values are taken. While the complete parameters that the authors took in this study are recorded in Table 1.

| No. | Item                        | Value |
|-----|-----------------------------|-------|
| 1   | Number of antenna elements  | 16    |
| 2   | Space between elements, \( d \) (in \( \lambda \)) | 1.0   |
|   | Description                                      | Value            |
|---|--------------------------------------------------|------------------|
| 3 | Number of iterations                             | 1000             |
| 4 | Angular response domain (in degree)              | -90 to +90       |
| 5 | Main signal angle (in degree)                    | +20              |
| 6 | The angle of the interference source (in degree) | +60              |
| 7 | SNR (in dB)                                      | 30               |
| 8 | Step size, $\mu$                                 | 0.01; 0.1; 0.5    |

4. Result and Discussions

Figure 4. Result for $d=0.5; \mu=0.1$

Figure 5. Result for $d=1; \mu=0.01$

Figure 6. Result for $d=1; \mu=0.5$
From the last three figures, one can see the number of nulling has doubled from 8 to 16 points with a growth in the spacing between the elements from half lambda to lambda. This is related to the better radiation pattern where the pattern forms a narrower beam (pencil). This is positive for a rise in the directivity of the antenna, which also means an increase in gain. Meanwhile, increasing the step size parameter (µ) from 0.01 to 0.5 will further improve the minimum error that occurs. In addition, the number of iterations mandatory to obtain the minimum error becomes smaller as the step size increases. In this situation, the quantity of iterations is around 400, and 70 times the desired MSE has occurred compared to the initial iterations taken at 1000 times when the step size is small, which is 0.01 which only results in MSE ranging from \(10^{-10}\). MSE of \(10^{-34}\) occurs at step size 0.5. From the amplitude response pattern following beam formation, the location of the central signal (0 dB) is accurate at an angle of 20° and 15 nulling positions are generated for 16 antenna elements at a spacing of \(\lambda\). The source of interference is eliminated/closed by placing the nulls in the path of the interference source at the 60° position with the nulls level in the range -90 dB to -325 dB at the value of the step size taken.

5. Conclusion
Simulations and observations have been carried out. In smart antenna beamforming where the NLMS algorithm is selected, with the equal number of M elements and the same spacing between elements, the experiment of increasing the \(\mu\) step size will simplify the amount of iterations to get a better MSE. And the spacing between antenna elements is generally taken to be half the wavelength in this case it produces a directivity that is not better than a distance of one wavelength.

References
[1] V.V. Sawant, and M.S. Chavan, “Performance of Beamforming for Smart Antenna Using Modified LMS Algorithm,” International Journal of Engineering Research and Science & Technology, vol. 2, no. 3, 2013.
[2] I. Stevanovi´c, A. Skrivervik and J.R. Mosig, “Smart Antenna Systems for Mobile Communications,” Final Report, Laboratoire d’Electromagnétisme et d’Acoustique Ecole Polytechnique Fédérale de Lausanne, Lausanne, Suisse, 2003. http://lemawww.epfl.ch/
[3] R. Sahu, R. Mohan, and S. Shrama, “Evaluation of Adaptive Beamforming Algorithm of Smart Antenna,” International Journal of Emerging Technology and Advanced Engineering, vol. 3, no. 9, 2013.
[4] K. Zarifi, and A. Ghrayeb, “Collaborative Null-Steering Beamforming,” IEEE Transactions on Signal Processing, vol.58, no.3, pp.1889-1903, 2010.
[5] Y. Zheng, “Adaptive Antenna Array Processing for GPS Receivers”. Thesis, University of Adelaide, South Australia, 2008.
[6] A. Khazzaz-Zalmenj, S.A. Vorobyov, and A. Hassanien, A. “Robust Adaptive Beamforming Based on Steering Vector Estimation With as Little as Possible Prior Information,” IEEE Transactions On Signal Processing, vol. 60, no. 6, pp.2974-2987, 2012.
[7] http://www.labbookpages.co.uk/audio/beamforming/delaySum.html#pattern
[8] R.Hidayat, Rushendra and E. Agustina, “Digital Beamforming of Smart Antenna in Millimeter Wave Communication,” IEEE 2017 International Conference on Broadband Communication, Wireless Sensors and Powering (BCWSP). https://ieeexplore.ieee.org/abstract/document/8272564/
[9] R.Hidayat, H.Setiawan, Y.Liklikwatil, S.Santoso, and N.S. Lestari, “Antena Cerdas Untuk Mitigasi Interferensi Dengan Algoritma Least Mean Square,” Jurnal Ilmiah Setrum, vol.6, no.1, pp. 97-105, 2017.
[10] D.L. Jones, “Adaptive Filters,” Connexions, Rice University, Houston, Texas. http://cnx.org/content/col10280/1.1/
[11] R. A. Asghar, A. Zar, “Matlab Simulator for Adapter Filters,” Tesis, Department of Electrical Engineering, School of Engineering, Blekinge Tekniska Högskola, Sweden.