Efficient combined fuzzy logic and LMS algorithm for smart antenna

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ABSTRACT

The smart antennas are broadly used in wireless communication. The least mean square (LMS) algorithm is a procedure that is concerned in controlling the smart antenna pattern to accommodate specified requirements such as steering the beam toward the desired signal, in addition to placing the deep nulls in the direction of unwanted signals. The conventional LMS (C-LMS) has some drawbacks like slow convergence speed besides high steady state fluctuation error. To overcome these shortcomings, the present paper adopts an adaptive fuzzy control step size least mean square (FC-LMS) algorithm to adjust its step size. Computer simulation outcomes illustrate that the given model has fast convergence rate as well as low mean square error steady state.

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1. INTRODUCTION

The smart antenna technique [1]-[3] is an integration of the array of antenna together with the digital signal processing in order to automatically optimize the radiation pattern in response to environment of the signal. System design encompasses the scheme of adaptive beamforming that generates the desired weight vector in order to produce the main beam into direction of user demand with null or attenuation at interfering signal direction. Least mean square (LMS) algorithm is considered as one of the best prosperously beamforming algorithms in adaptive antennas, essentially owing to its low computational complexity [4]-[6]. The conventional least mean square (C-LMS) algorithm exploits a fixed step size in order to amend its weight filter tap as a response to the altered situation. However, a small step size leads to small fluctuation error steady-state in addition to slow convergence [7], [8]. On the other hand, opposite effect is obtained at applying a large step size. Consequently, the step size assignment is usually a trade-off between rapid convergence and low steady-state fluctuations. Several methods are proposed to offer adaptive step size methodologies for LMS algorithm, their quintessence idea might involve variable step size least mean square algorithm (VSLMS) and variable step size normalized least mean square algorithm (VSNLMS) [9], or complex weights' adjustment for the LMS using a variant called fractional LMS (FLMS) [10], while Kalman recursive least square-least mean square (KRLMS) has been proposed in [11]. In this context, the fuzzy control algorithms are used to perform the appropriate input data vector mapping into a scalar step size assessment [12]-[15]. As a consequence to its richness and flexibility many different mappings could be accomplished. In this paper, based on fuzzy control and LMS algorithms, a new integrated algorithm is adopted for smart antennas named (FC-LMS) algorithm.

2. SYSTEM MODEL

Assume a system of a smart antenna array holds an elements number (N), with an identical distance between every two consequence elements, contains an adaptive beamforming algorithm that work under a digital signal processor [16] as illustrated in Figure 1. The smart antenna array receives a total signal vector $\mathrm{X}(k)$ as [17]:

$$\mathrm{X}(k) = s_d(k)a(\theta_d) + \sum_{i=1}^{L} s_i(k)a(\theta_i) + n(k) \\ = [\, x_1(k),\ x_2(k), \ldots, x_N(k)\,]^T \quad (1)$$

Where $s_i(k)$ and $s_d(k)$ identify the interfering and desired signals that arrive at angles of θ_i and θ_d to the array respectively, while L identifies the interfering signals number and n represents the array elements white Gaussian noise, whereas $a(\theta_i)$ and $a(\theta_d)$ represent the steering vectors for interfering and desired signals respectively.

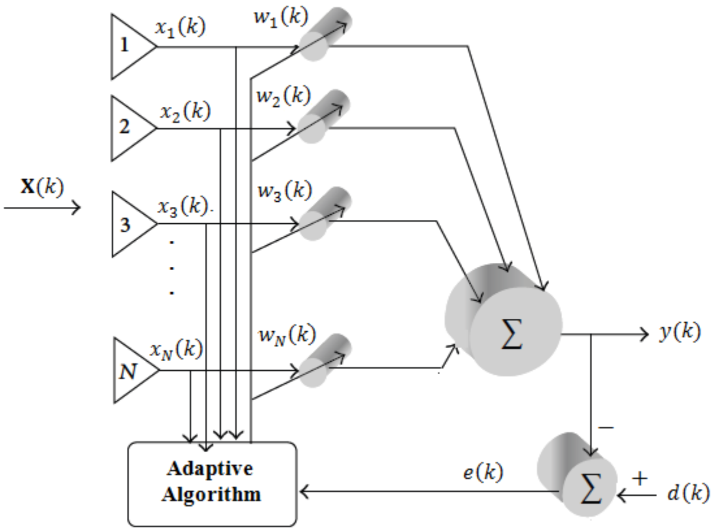


Figure 1. Structure of adaptive beamforming algorithm

As illustrated in Figure 1, the individual elements output are combined linearly after scaled by the correspondent weights, in such a way that the smart antenna array will hold nulls in the interferers directions and maximum possible gain in the desired signal direction. The system issue implicates the desired signal estimation from received signal through minimizing the error of the output signal and the reference signal which is nearly matches the desired signal estimation. On the other hand, the smart antenna array output at k th iteration can be obtained by [18]-[21]:

$$y(k) = \mathrm{W}^T(k)\,\mathrm{X}(k) \quad (2)$$

Where $\mathrm{W}(k)$ is weight vector whose need to adjusted to optimization the radiation pattern and expressed as:

$$\mathrm{W}(k) = [\, w_1(k), w_2(k), \ldots\ldots, w_N(k)\,]^T \quad (3)$$

These weights are calculated utilizing least mean square algorithm depending on minimum squared error (MSE) principles, then weight coefficients are adjusted according to the equation [22], [23]:

$$\mathrm{W}(k+1) = \mathrm{W}(k) + \mu e^*(k)\,\mathrm{X}(k)^T \quad (4)$$

Since μ represents step size and $e(k)$ is the error signal that utilized in order to adjust the adaptive system using weight vector optimization as [24], [25]:

$$e(k) = d(k) - y(k) \quad (5)$$

While $d(k)$ represents the reference signal, which is utilized as the desired response from adaptive processing that associated with elements of antenna array that lead beamformer to place the main beam toward the identified direction only. In conventional LMS (C-LMS) algorithm, μ step size is fixed parameter at all iterations and limited by Horowitz Senne equation [26]:

$$0 < \mu < \frac{2}{3NP_x} \tag{6}$$

While N represents tap weight number of the adaptive filter, whereas P_x identifies the input power. However, step size selection process is critical, a small step size gives lower minimum squared error but slower rate of convergence, and vice versa [27], [28]. Furthermore, larger step size is required to accommodate fast rate of convergence. In contrast, small step size is required in order to accommodate low steady minimum squared error. In general, the C-LMS algorithm fails to offer acceptable response in smart antenna array system.

3. PROPOSED MODEL

The proposed model incorporates the fuzzy system control with LMS algorithms (FC-LMS) for smart antenna system as displayed in Figure 2. In this proposed model, the fuzzy control algorithm is used for step size adjustment in the LMS algorithm at each iteration (i) in order to obtain a new convergence weight that compose the beam in the desired direction. The proposed model use both squared error $e^2(k)$ besides squared error variation $\Delta e^2(k)$ at the kth iteration as an inputs to the fuzzy control system to get the output $\mu(k)$ using Mamdani minimum inference method and centroid defuzzification process.

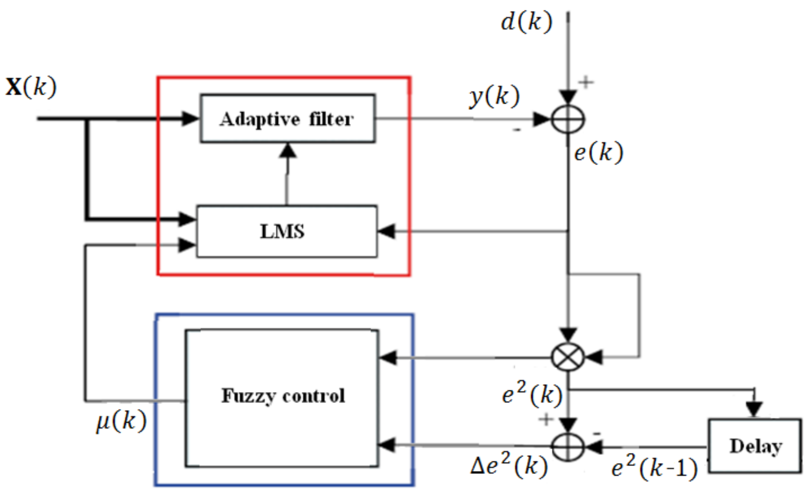


Figure 2. Block diagram of FC-LMS algorithm for smart antenna

More specifically, the following steps are performed in the present model:
- Step 1: the vector x of (1) is obtained via signal array vector.
- Step 2: initialize the LMS algorithm weight.
- Step 3: estimate the output of the LMS algorithm according to (2).
- Step 4: compute the squared error $e^2(k)$ depending on (5) and the squared error variation $\Delta e^2(k)$ relevant to:

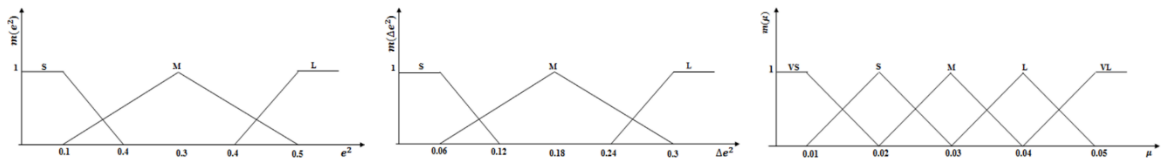
$$\Delta e^2(k) = |e^2(k) - e^2(k-1)| \tag{7}$$

- Step 5: the LMS algorithm step size is adjusted using the fuzzy controller which takes these two inputs $[e^2(k), \Delta e^2(k)]$ to compute the output $\mu(k)$:

$$FC - LMS: (\mu(k)) = FL[e^2(k), \Delta e^2(k)] \tag{8}$$

- Step 6: update the LMS weights according to (4).
- Step 7: repeat steps 2 to 6 until getting the optimum results.

The present fuzzy controller model comes from the human experience in the practical applications and system experiments. Figure 3(a) and Figure 3(b) shows the membership functions of the proposed FC-LMS algorithm. In which; three linguistic variables are related for every fuzzy input; named; small (S), medium (M), and large (L); in addition to five linguistic variables for fuzzy output Figure 3(c) to get more accuracy, very small (VS), small (S), medium (M), large (L), very large (VL) to construct a set of fuzzy IF-THEN rules that shown in Table 1.



(a) (b) (c)

Figure 3. Membership functions of the proposed fuzzy model (a) squared error fuzzy input, (b) variation squared error fuzzy input, and (c) step size fuzzy output

Table 1. Predicate rule box for the FLC-LMS

μ		e^2		
		S	M	L
Δe^2	S	VS	S	M
	M	S	M	L
	L	S	M	VL

4. SIMULATION AND RESULT

Computer simulation has been carried out using Matlab to investigate the effectiveness of the proposed model for smart antenna. A linear array is considered with these specifications: antenna element numbers in the array equal 8; spacing of inter element in the array is 0.5 λ. While the desired signal direction is 0°; and the unwanted signal direction 50° and -30°; and lastly the number of iterations taken is 200.

Figure 4 presents the obtained radiation pattern of the proposed model as compared with C-LMS at $\mu = 0.001$. From this acquired figure; it can observe that both comparative algorithms direct the main beam toward the direction of the wanted signal at 0° with null toward the directions of unwanted signals. More specifically, FC-LMS model sets nulls toward both interferer, in which; -54 dB null depth at 50° toward the first interferer in addition to -58 dB at -30° toward the second interferer as compared with null depth of -46 dB at 50° toward the first interferer and -32 dB at -30° toward the second interferer in the conventional algorithm, which offers a significant improvement when applying the proposed algorithm by about 8 dB and 26 dB in interference suppression at 50° and -30° respectively.

On the other hand, Figure 5 reveals the MSE curve for each algorithm, which can be clearly demonstrated that the proposed FC-LMS algorithm can attain faster convergence than the conventional algorithm. While Figure 6 illustrates the weight magnitude for each algorithm, which observes that the weight in the proposed algorithm converges to the optimal value more quickly as compared with the C-LMS algorithm. And finally Figure 7 reveals the desired signal acquisition and tracking for each algorithm, which observed that the response of the proposed algorithm without fluctuation as compared with the C-LMS algorithm.

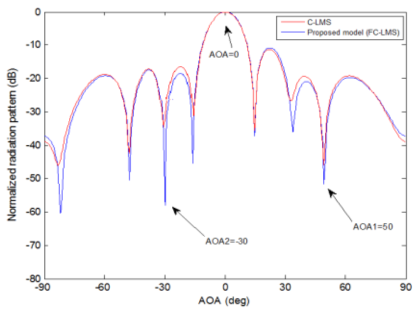


Figure 4. Radiation patterns for CLMS and proposed algorithm (FC-LMS)

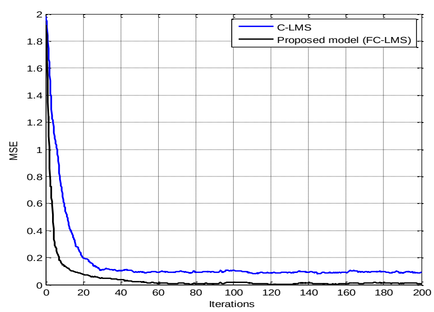


Figure 5. Mean square error for CLMS and proposed algorithm (FC-LMS)

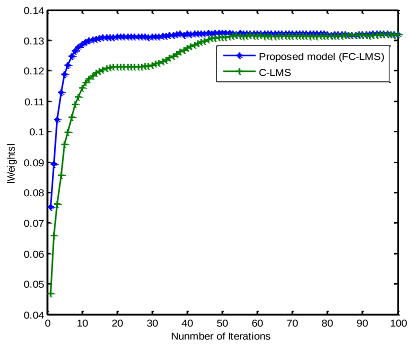


Figure 6. Weight magnitude for the proposed algorithm and C-LMS algorithm

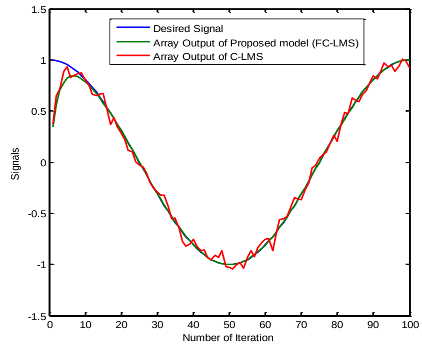


Figure 7. Desired signal acquisition and tracking for proposed algorithm and C-LMS algorithm

From Figure 4, Figure 5, Figure 6 and Figure 7; we can conclude that the adopted scheme drive the main beam towards the interested signal and efficiently preserve the nulls towards the noninterested signals. It also reveals better outcomes in terms of depth nulls and side lobes' levels in undesired directions. In addition to faster convergence speed as compared to the conventional algorithm.

5. CONCLUSION

The current paper presents a new model that integrates the fuzzy control besides least mean square algorithm to improve the response of smart antenna. In the proposed model, the fuzzy logic controller is employed to update the step size in the least mean square algorithm for smart antenna. The achieved simulation results in smart antenna demonstrate that the proposed model attains considerable improvement in terms of convergence time, inference suppression in addition to low steady-state MSE as compared to C- LMS.

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