Improvement of Applebaum Array Interference Cancellation in Smart Antenna System by Using Covariance Matrix Adjustment

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Abstract: This paper proposes the interference cancellation improvement in smart antenna system by using Applebaum array covariance matrix adjustment. This technique adds the specific adjustable multipliers with both desired signal covariance matrix and interference signal covariance matrices in order to overcome some disadvantages and improve the interference cancellation efficiency of Applebaum array. It is based on the desired and undesired signal power or desired signal-to-interference-plus-thermal noise ratio (SINR). As the result from demonstration, the proposed technique can improve and increase the interference cancellation efficiency in smart antenna better than the conventional technique.

1. Introduction

Smart antennas have recently received increasing a role for using to improve the performance of wireless communication systems [1]. These systems of antennas are composed of many components. The one important component is beam-forming system that attempts to enhance the desired signal and suppress the interference signals. Among the various beam forming schemes of smart antenna systems, the least mean square (LMS) array and the Applebaum array algorithms proposed by Widrow, *et al.* and Applebaum [2], respectively, have been attracted considerable attention from various researchers. The LMS array uses the comparison between the output and reference signals to pursue the minimization of the mean square error (MSE), whereas the Applebaum array endeavors to seek the maximization of the desired signal-to-interference-plus-thermal noise ratio (SINR). The LMS array requires the desired signal waveform, however, it does not need its incident angle knowledge. On the contrary Applebaum array can be used when the incident angle of the desired signal is known [2]-[5].

In practice, the convergence rate and the performance of the system in adaptive array are important to perform its usefulness. The Applebaum array has the advantages in its simple hardware structure and fast convergence time. However the convergence time could be extremely long when multiple interference signals, causing an eigenvalue spread, are incident on the array. But this disadvantage can be overcome by using the Gram-Schmidt preprocessor, the sample matrix inversion (SMI) [3] etc. These methods require large number of computations and very complex hardware.

If interference signals could be distinguished according to their relative power level, the Applebaum array could effectively remove all interference signals regardless of the eigenvalue spread of the input signal covariance matrix [3]. However when the interference to noise ratio (INR) level in Applebaum array decreases and fluctuates, the null response in the interference direction will be disturbed and throb. Hence the null response direction is not exactly in the interference direction, resulting in the declined performance of interference cancellation.

According to the aforementioned of interference cancellation disadvantage, this paper proposes the covariance matrix adjustment technique to solve that problem. When there is an incident interference signal at the array antenna, the proposed technique will add and adjust the multipliers of the interference signal and desired signal covariance matrices in weight computation for setting exact deep null response in interference signal directions and high response in desired signal direction which can improve the weak signal problem.

This paper includes the conventional Applebaum array theorem in section 2, covariance matrix adjustment technique in section 3, computer simulation results in section 4 and finally the conclusions in section 5.

2. Conventional Applebaum Array

The concept of Applebaum array begins with the optimization criterion by considering the analytic signals $\bar{x}_i(t)$ of an N-element adaptive array and complex weights w_i as shown in Figure 1, where θ is the angle of arrival.

From Figure 1, the analytic signal $\bar{x}_i(t)$ [6], which may consist of desired signal term, interference term and noise term as

$$X = X_d + X_i + X_n \,. \tag{1}$$

They are multiplied by complex weights w_i, then summed to be the output signal $\bar{s}(t)$ [2], [7]. It can be expressed as

$$\bar{s}(t) = W^T X = \bar{s}_d(t) + \bar{s}_i(t) + \bar{s}_n(t) \tag{2}$$

with a vector form that under narrow-band uncorrelated jamming sources assumption [2], [3].

The weight vector optimization in Applebaum array is based on maximization of SINR where

$$SINR = \frac{P_d}{P_u} = \frac{P_d}{P_i + P_n} \,. \tag{3}$$

P_d, P_u, P_i and P_n are desired signal power, undesired signal power, interference signal power and noise power, respectively.

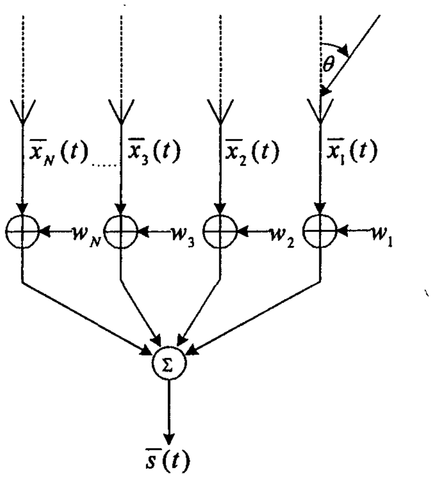

Figure 1. An N-element adaptive array.

where q can be either d, u, i or n. At the steady state, optimal weight vector of Applebaum array converges to Wiener-Hopf equation [3] that is given as

$$W_{opt} = \mu\Phi^{-1}U_d^* \tag{5}$$

where μ, U_d^* and Φ represent an arbitrary constant, desired signal and input covariance matrix, respectively. Φ can be defined as

$$\Phi = \mathrm{E}(X^* X^T) = \mathrm{E}(X_d^* X_d^T) + \mathrm{E}(X_i^* X_i^T) + \mathrm{E}(X_n^* X_n^T)$$
$$= \Phi_d + \Phi_i + \Phi_n . \tag{6}$$

In the Applebaum array, the interference signal power level is important for interference cancellation beam-forming. When the interference to noise ratio (INR) level is diminished [3], the output SINR pattern response of Applebaum array at the interference direction will be affected. The output null pattern response will not exactly be at the interference direction. In this case, the interference cancellation efficiency is decreased. Although there is the arbitrary constant μ that can adjust weight vector in (5), it can not specify the multiplier in each covariance matrix both interference signal covariance matrix Φ_i and desired signal covariance matrix Φ_d, which have different interference to noise ratio (INR) and signal to noise ratio (SNR), respectively. Thus, adjusting arbitrary constant is not the efficient technique to solve the disadvantage. For this reason, when the interference to noise ratio (INR) level is small, the interference cancellation capability of conventional Applebaum array is decreased.

3. Covariance Matrix Adjustment Technique

According to the disadvantage of the conventional Applebaum array that occurs when the INR level of the interference signal decreases or the noise increases, we propose the covariance matrix adjustment technique to improve that mentioned disadvantage. This proposed covariance matrix adjustment technique is the process that adds the adjustable multipliers to the covariance matrix both interference signal covariance matrix Φ_i and desired signal plus noise covariance matrix Φ_{dn}, in the complex weight analysis, for controlling output null response in the interference signal directions and output peak response in the desired signal direction. In this proposed technique, the desired signal plus noise covariance matrix consists of both desired signal term and noise term ($\Phi_{dn} = \Phi_d + \Phi_n$). The proposed adjusted covariance matrix (Φ_{adj}) is defined as

$$\Phi_{adj} = B\Phi_{dn} + C\Phi_i . \tag{7}$$

Since B multiplies with the desired signal and noise covariance matrix, therefore B has to be added in complex weight calculation and C will multiply with the interference covariance matrix, when there is the interference. The value of B and C depend on the value of input signal to noise ratio (SNR) and input interference to noise ratio (INR), respectively. If there are the interference signals from many directions, the interference covariance matrix will be consisted of many interference covariance matrices. In this case, it is assumed that we knew the directions of desired signal and interference signals from the direction of arrival (DOA) [8] estimation (such as MUSIC, ESPRIT, etc. [9]-[11]). For example, if there are the interference from three directions, Φ_i will consist of Φ_{i1}, Φ_{i2} and Φ_{i3}. Hence, C will consist of C_1, C_2 and C_3 that can be expressed as

$$\Phi_{adj} = B\Phi_{dn} + C_1\Phi_{i1} + C_2\Phi_{i2} + C_3\Phi_{i3} . \tag{8}$$

In this regard, if each input INR of interference signal is different, each C_i of interference covariance matrix will not be the same. To obtain high SINR pattern response in the desired signal direction and the exact null response in the interference signal directions, the value of B must be small because the desired signal is only present for a short period of time [3], whereas the value of C_i is large to increase the interference covariance matrix that decreases output SINR pattern response in the interference directions. The value of B and C are considered from the input signal of the system. Thus, it is necessary to have the control operation for comparing the input signal level and its threshold. The value of B and C can be considered from Figure 2 and Figure 3 which are the examples of relation between the level of output SINR and B at various C values in the 30^0, 40dB SNR desired signal and 60^0, 30dB INR interference signal case. Figure 2 and Figure 3 illustrate that the output desired direction SINR and the output interference direction SINR are proportional and inverse proportional with the value of B and C, respectively. To minimize output interference direction SINR and keep the output desired direction SINR closed to the maximum value, B and C can be set to 0.002 and 30, respectively while SNR value of desired signal and INR value of interference signal are between 10dB and 50dB.

When the level of SNR and INR of the desired signal and interference signal, consecutively change, B and C will change in the opposite manner. If SNR and INR increase,

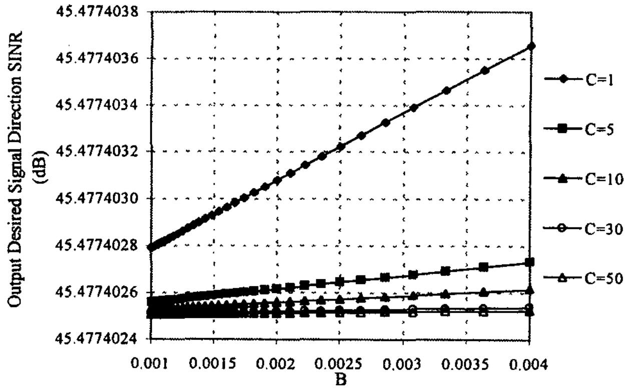

Figure 2. The comparison of output desired direction SINR versus *B* for various *C* values of 30^0 40dB SNR desired signal and 60^0 30dB INR interference signal.

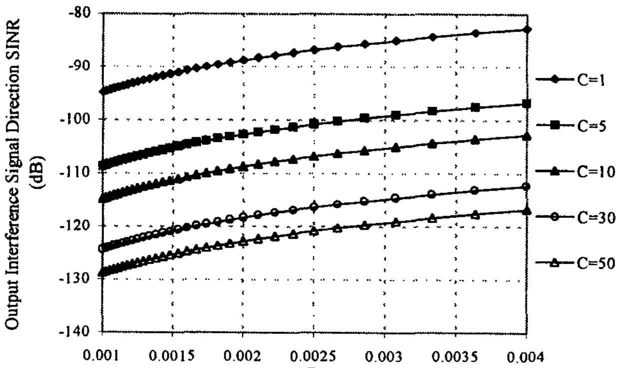

Figure 3. The comparison of output interference direction SINR versus *B* for various *C* values of 30^0 40dB SNR desired signal and 60^0 30dB INR interference signal.

the value of *B* and *C* will be decreased. On the contrary, if SNR and INR decrease, the value of *B* and *C* will be increased.

The operation of covariance matrix adjustment technique in Applebaum array begins with DOA receives the input signal to estimate the signal directions. The next process is the decision part for considering the number of interference signals. If there is not any interference, the adjusted covariance matrix will be set as desired signal covariance matrix, then its determinant is checked. The covariance matrix will be inverted (Φ^{-1}) in the complex weight computation [2], thus the covariance matrix should be the nonsingular matrix ($\det(\Phi) \neq 0$). The important cause of singular matrix problem is the signal reduction or the weakness of the signal [3] that can be improved by readjusting covariance matrix in order to increase the value of *B* and *C*. In addition, this technique has to consist of degree of freedom [2] decision to divide and choose the interference in the suitable direction. Because the number of null response pattern direction that can be set for interference cancellation of the linear array system is equal to the degree of freedom (N-1) [2], where N is the number of the array element. If the number of interference is more than the degree of freedom, it is necessary to choose the suitable interference from the consecutive high INR level.

After the adjusted covariance matrix is obtained, the complex weight can be computed. We can then see that the weight solution of the improved covariance matrix adjustment technique in Applebaum array will multiply with the input signal in each branch of the array and summed to be an output signal.

4. Computer Simulation Results

In this section, the Applebaum array interference cancellation performance of the covariance matrix adjustment technique in SINR pattern response is clarified by computer simulations and shows that null response can be improved in the interference signal directions. To compare the performance of the proposed covariance matrix adjustment technique in Applebaum array with the conventional Applebaum array, we consider the Applebaum array consisting of four isotropic elements with half wavelength apart between elements. The maximum number of incident interference signals that can be rejected is equal to the degree of freedom that is N-1 or three.

When there are three interference signals with same interference to noise ratio (INR) of 30dB from incident angles of -70^0, -50^0 and 50^0 with 40dB SNR desired signal from incident angle of -10^0, the SINR response pattern of the conventional Applebaum array and the proposed technique can be presented in Figure 4. It represents more effective null response setting in the interference signal directions of proposed technique than the conventional Applebaum array.

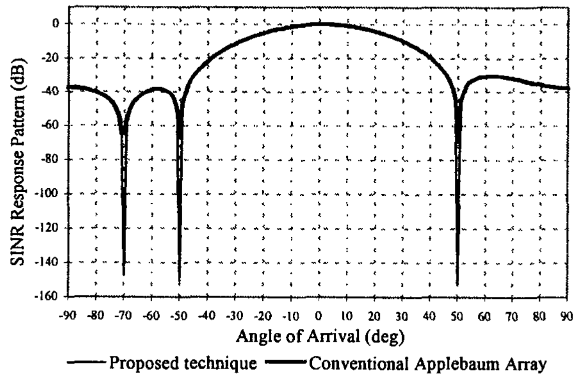

Figure 4. SINR response pattern of Applebaum array of -10^0, 40dB SNR, desired signal with three interference signals at -70^0, -50^0 and 50^0 with the same 30dB INR.

From Figure 5, the output SINR response pattern in the interference directions of conventional Applebaum array is fluctuated and not accurate, when the weakness of the signal problem occurs in the conventional Applebaum array. It is found that the SINR response pattern of the proposed covariance matrix adjustment technique is still set exact null response pattern in the interference directions. In Figure 5, there are three interference signals with same interference to noise ratios of 15dB come from incident angles of -70^0, -50^0 and 50^0 with 40dB signal to noise ratio (SNR) desired signal comes from incident angle of -10^0.

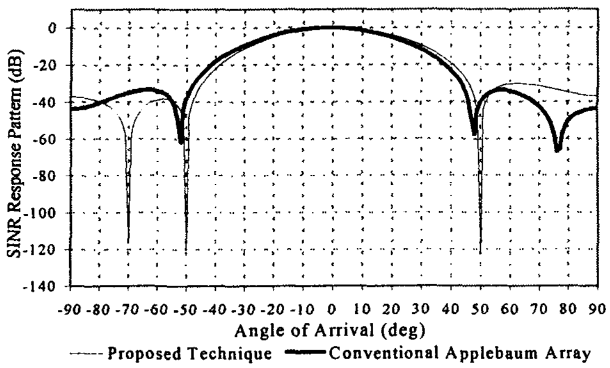

Figure 5. SINR response pattern of Applebaum array of -10^0, 40dB SNR, desired signal with three interference signals at -70^0, -50^0 and 50^0 with the same 15dB INR.

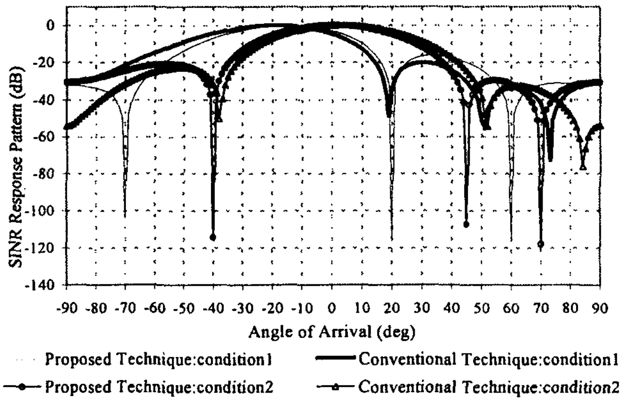

Figure. 6 The comparison of SINR response pattern between the conventional Applebaum array and the proposed technique for two conditions, (condition 1: -40^0 40dB SNR desired signal and three interference signals -70^0, 20^0 and 60^0 with 10dB, 10dB and 15dB INRs, respectively; condition 2: 20^0 40dB SNR desired signal and three interference signals -40^0, 45^0 and 70^0 with 10dB, 10dB, and 15dB INRs, respectively).

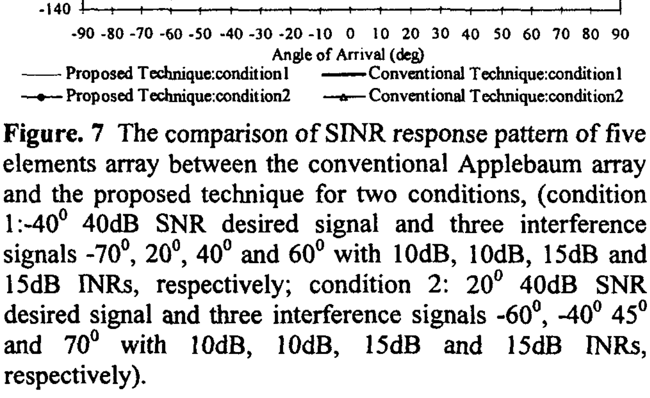

Figure. 7 The comparison of SINR response pattern of five elements array between the conventional Applebaum array and the proposed technique for two conditions, (condition 1:-40^0 40dB SNR desired signal and three interference signals -70^0, 20^0, 40^0 and 60^0 with 10dB, 10dB, 15dB and 15dB INRs, respectively; condition 2: 20^0 40dB SNR desired signal and three interference signals -60^0, -40^0 45^0 and 70^0 with 10dB, 10dB, 15dB and 15dB INRs, respectively).

In case of other desired signal and interference signal directions, the results of the proposed interference cancellation technique are still more effective than the conventional Applebaum array, that can be clarified in Figure 6. In addition, the number of the array element is an important factor that has a role to increase the interference cancellation efficiency. When the number of array element is increased, the degree of freedom in this Applebaum array increases in the same trend. This should increase interference cancellation efficiency because it can reject more incident interference signals that come from many directions than less array elements. It can be shown in Figure 7 which demonstrates that although the number of array element is increased the propose Applebaum covariance matrix adjustment technique can still set null response pattern in the interference directions better than the conventional Applebaum array.

5. Conclusions

The computer simulation results illustrate that the proposed covariance matrix adjustment technique can improve Applebaum array interference cancellation in smart antenna system. Although, there are many incident interference signals as much as the degree of freedom of the system, the proposed covariance matrix adjustment technique can solve the weak signal problem for the interference rejection. Moreover, this technique can be effectively used with many element numbers of Applebaum array.

References

[1] M. Chryssomallis, "Smart Antenna," *IEEE Antennas and Propagation Magazine*, vol. 42, no. 3, pp. 129-136, June 2000.

[2] R. T. Compton, Jr., *Adaptive Antennas Concepts and Performance*, Prentice-Hall, Englewood Cliffs, NJ, 1988.

[3] K. M. Lee and D. S. Han, "AGC Applebaum Array for Rejection of Eigenvalue Spread Interferences," *IEICE Trans. Commun.*, vol. E84-B, no. 6, pp. 1674-1678l, June 2001.

[4] Y. Ogawa and T. Ohgane, "Advances in Adaptive Antenna Technologies in Japan," *IEICE Trans. Commun.*, vol. E84-B, No. 7, pp. 1704-1712, July 2001.

[5] G. V. Tsoulos, "Smart Antennas for Mobile Communication Systems: Benefits and Challenges," *Electronics & Communication Engineering Journal*, pp. 84-94, Apr. 1999.

[6] H. Krim and M. Viberg, "Two Decades of Array Signal Processing Research," *IEEE Signal Processing Mag.*, pp. 67-94, July 1996.

[7] S.P. Applebaum, "Adaptive Arrays," *IEEE Trans. Antennas Propag.*, vol. AP-24, no. 5, pp. 585-598, Sept. 1976.

[8] B. Friedlander and B. Porat, "Performance Analysis of a Null-Steering Algorithm Based on Direction-of-Arrival Estimation." *IEEE Trans. Acous., Speech. Signal processing.*, vol. 37, no. 4, Apr. 1989.

[9] J. S. Jeong, K. Sakaguchi, K. Araki and J. Takada, "Generalization of MUSIC Using Extended Array Mode Vector for Joint Estimation of Instantaneous DOA and Angular Spread," *IEICE Trans. Commun.*, vol. E84-B, No. 7, pp. 1781-1789, July 2001.

[10] N. Yuen and B. Friedlander, "Asymptotic Performance Analysis of ESPRIT, Higher Order ESPRIT, and Virtual ESPRIT Algorithms," *IEEE Trans. Signal processing.*,vol. 44, no. 10, pp. 2537-2550, Oct. 1996.

[11] B. Friedlander and A. J. Weiss, "Direction Finding Using Spatial Smoothing With Interpolated Arrays," *IEEE Trans. Aeros., Electronic System.*, vol. 28, no. 2, pp. 574-587, Apr. 1992.