Improved Convergence Property of Adaptive Array in Mobile Environment

Mitoshi FUJIMOTO* and Toshikazu HORI
University of Fukui, 3-9-1, Bunkyo, Fukui, 910-8507 Japan
E-mail:{fujimoto, hori}@fuis.fuis.fukui-u.ac.jp

Abstract The convergence property of the Least Mean Squares adaptive array may degrade in mobile communication environments. This paper shows that the degradation in performance is fatal to the system. To avoid this degradation, a new method called "bracing" is proposed in which the weight coefficients are slightly shortened at each iteration. The results of computer simulations show that the proposed method yields comparable performance to that of the Recursive Least Squares algorithm.

Keywords: Adaptive Array, Mobile Environments, Continuous Control, LMS

1. Introduction

Adaptive arrays have been studied for use as countermeasures for multi-path and co-channel interference [1]. The Minimum Mean Square Error (MMSE) is a suitable algorithm for optimizing the weight coefficients of the adaptive array because it does not require a priori knowledge except for a reference signal. The Least Mean Squares (LMS) algorithm is a typical optimization method that does not generate a heavy computational load [2]. However, the convergence property of the LMS algorithm is extremely degraded in specific environments in which the directions of the arrival waves are close to each other.

A method that combines the LMS and Recursive Least Squares (RLS) has been proposed to avoid this problem [3]. The convergence speed of the system at the beginning of iteration is accelerated; however, the serious problem of variation in the radio environments after convergence of the algorithm still remains.

This paper first describes in detail the problem in which the convergence property of the LMS adaptive array is decreased in specific mobile communication environments, and then indicates how the degradation in performance is fatal to the system. Next, the new method called "bracing" is proposed as a countermeasure in which the weight coefficients are slightly shortened at every iteration. The results of computer simulations show that the proposed method yields comparable performance to that of the RLS algorithm.

2. Degradation of Convergence Property of LMS Adaptive Array

2.1 LMS Adaptive Array

We denote the received signals as x_k and the weight coefficients as w_k at each antenna element as follows. Here, K and T represent the number of antenna elements and the vector transposition, respectively.

$$\mathbf{X} = [x_1 \quad x_2 \quad \cdots \quad x_K]^T \tag{1}$$

$$\mathbf{W} = [w_1 \quad w_2 \quad \cdots \quad w_K]^T \tag{2}$$

The output signal of the array antenna is expressed as Equation (3), and the weight coefficients of the LMS adaptive array are updated based on Equation (4).

$$y = \mathbf{X}^T \mathbf{W}^* \tag{3}$$

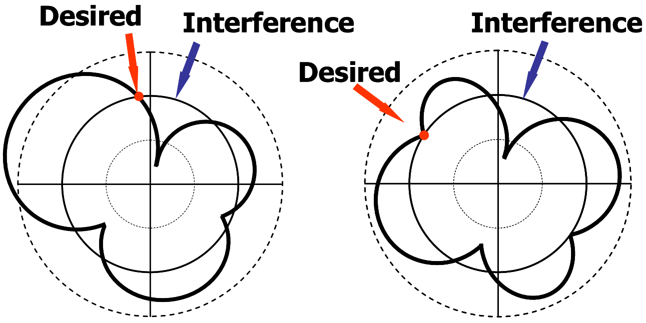
$$\mathbf{W}_{LMS}(n+1)=\mathbf{W}_{LMS}(n)+\mu\mathbf{X}(n)\,e^{*}(n) \tag{4}$$

Here, * indicates the complex conjugate. In Equation (4), μ denotes the step-size and e is the error signal between output signal y and reference signal r.

The operation volume of the LMS algorithm is considerably less compared to a high-speed algorithm such as RLS and Sampled Matrix Inversion (SMI). However, the convergence property of the LMS algorithm is extremely degraded in specific environments, for example, when the directions of the arrival waves are close to each other as described below.

2.2 Increase in Weight Coefficients

The weight coefficients should be controlled over a longtime when receiving a broadcasted signal. In this case, even though the variation in the arriving wave environment per update is very slight, the environment changes gradually which accumulates to a substantial change in comparison to the beginning of iteration. This causes a situation in which the interference waves cannot be suppressed by the adaptive array because the direction of the desired wave and that of the interference wave are close to each other as shown in Fig. 1(a). This situation cannot be resolved by adaptive arrays; however, it is expected that the problem will be resolved over the course of time by changing the environment further. In the case of the LMS adaptive array, the weight coefficients are also very large due to the gradual increase mentioned above, even though the directions of the arriving waves are far apart as shown in Fig. 1(b) and the convergence property is severely degraded. Since this phenomenon certainly occurs in a mobile environment, this problem is a serious issue that must be addressed for the LMS adaptive array.



(a) DOA is closed (b) Dilated coefficients

Fig. 1 Directional patterns of array (Concept)

3. Bracing to improve convergence property

When the weight coefficients are large, Additive White Gaussian Noise (AWGN) is enhanced. To reject the enhanced AWGN, thousands of iterations are needed because the LMS adaptive array is insensitive to noises that do not have direction. To shorten the time until the AWGN is rejected, we add the force of bracing to the weight coefficients. More concretely, the weight coefficients are updated based on Equation (5) instead of Equation (4).

$$\mathbf{W}_{LMS}(n+1)=\beta\cdot\mathbf{W}_{LMS}(n)+\mu\,\mathbf{X}(n)\,e^{*}(n) \tag{5}$$

Here, value β is set at a value that is slightly less than 1.0, and we call β the “bracing factor” hereafter. Equation (5) represents a situation in which the weight coefficients are slightly braced whenever the coefficients are updated. As a result, it is anticipated that the convergence speed will be accelerated by shortening the radiation pattern without changing the relative pattern of the array antenna.

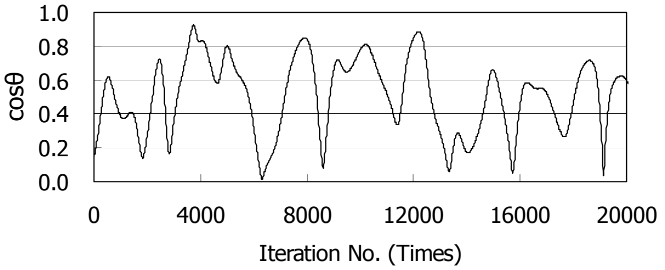
4. Convergence property of proposed method (Computer simulation)

To confirm the effect of the proposed method, we conducted a computer simulation. In the simulation, we assumed that the system has four antenna elements and the number of arriving waves is two (desired wave and interference wave). It assumed that there is no correlation in the fading at the antenna elements and that the maximum Doppler frequency is $f_d T = 4.88 \mathrm{X} 10^{-4}$. This corresponds to a case in which the velocity of the mobile terminal is approximately 50 km/h when the carrier frequency and symbol rate are 2 GHz and 192 ksymbol/sec, respectively. Furthermore, we adopted the value of 0.995 as the bracing factor.

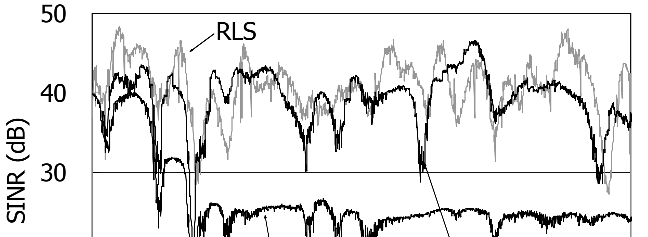
Figure 2(a) shows the fluctuation in the angle difference of the directional vector of the arriving waves, and Fig. 2(b) shows the variation in the Signal to Interference plus Noise power Ratio (SINR). The figures show that:

1) Approximately 40 dB of the SINR can be obtained at the start of iteration for all algorithms.
2) The SINR value sharply decreases at approximately 4,000 iterations where the $\cos\theta$ is large. We cannot address such a situation by using an array antenna because the arrival directions of the two waves are close to each other.
3) After $\cos\theta$ decreases, the SINR value of the proposed method recovers immediately.

The above results show that the proposed bracing method is fundamentally effective in improving the convergence property of the LMS adaptive array in a mobile radio environment, and that it exhibits comparable performance to the RLS algorithm.



(a) Variation of angle difference



(b) Variation of SINR

Fig.2 Convergence property (Simulation results)

It is obvious that bracing factor β affects the performance of the proposed system. Thus, we evaluated the effects of the bracing factor by drawing approximate curves of the relationship between $\cos\theta$ and the SINR. The results are shown in Fig. 3. The horizontal axis indicates the bracing factor, the depth denotes $\cos\theta$, and the height is the obtained SINR value.

When β is close to 1.0, the SINR value decreases due to the enlarged weight coefficients because the case is similar to that of the conventional LMS. On the one hand, an excessively small β value causes the SINR value to be small because the weight coefficients became too small. Figure 3 indicates that the optimum bracing factor is approximately 0.998.

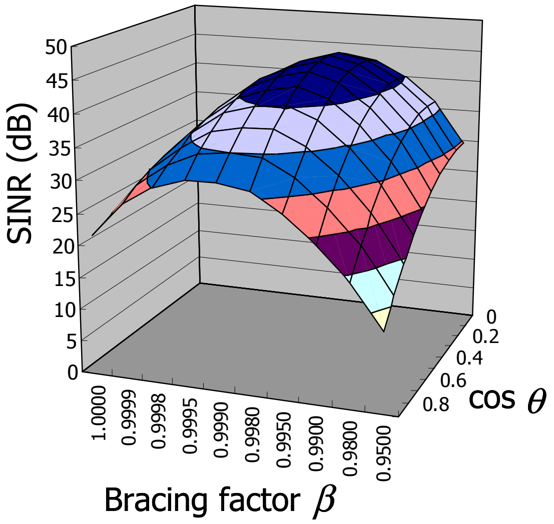


Fig.3 Effect of bracing factor on SINR

5. Conclusion

A bracing method was proposed in which the degradation in the convergence property of the LMS adaptive array can be avoided by shortening the weight coefficients. The simulation results showed that the proposed method is effective in improving the convergence property and it exhibits comparable performance to the RLS algorithm in mobile communication environments. Numerical evaluation showed that the optimum bracing factor is approximately 0.998.

Since the proposed method maintains the features of the LMS algorithm, which has a low computation load, we consider that the proposed method is useful in mobile reception of digital broadcasting.

References

[1] "Special Issue on Adaptive Array Antenna Techniques for Advanced Wireless Communications Signal Processing Technology in Antennas," IEICE Trans. Commun., vol. E84, no. 7, pp. 1703-1875, July 2001.

[2] S. Haykin, Adaptive Filter Theory, Third Edition, Prentice-Hall, Inc., 1996.

[3] Y. Ogawa, M. Ohmiya, and K. Itoh, "An LMS Adaptive Array for Multipath Fading Reduction," IEEE Tans. Aerosp. & Electron. Syst., vol.AES-23, pp.17-23, Jan. 1987.

[4] H. Ichige, M. Shimizu, H. Arai, "Combination of Optimization Algorithms for MMSE/CMA Adaptive Antenna Array, IEICE Tech. Report, AP2003-61, pp.121-126, 2003.