DIRECTIONALLY CONSTRAINED ADAPTIVE ARRAY USING CONSTANT MODULUS ALGORITHM

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1. INTRODUCTION

The power-minimizing adaptive array tends to cancel the desired signal with the interference, if they are correlated with each other, as is usually the case in multipath environments[1],[2]. On the other hand, the constant modulus (CM) adaptive array[3],[4] has been developed which can maintain the desired signal having the constant modulus property such as FM, PSK or FSK signals even in the multipath environments. It is one of the advantages of the CM adaptive array that it does not need the *a priori* knowledge on the direction of the desired signal. However, since the optimization of the CM adaptive array is based on the LMS (Least Mean Square) algorithm using the steepest descent method, we require such knowledge to set the best initial weights that steer a main beam in the direction of the desired signal[5]. Therefore, assuming that we know the direction of the desired signal, we propose the CM adaptive array operating under a directional constraint, and demonstrate its better transient performance by computer simulation.

2. CM ADAPTIVE ARRAY UNDER A DIRECTIONAL CONSTRAINT

We consider a K-element adaptive antenna array. Let $\mathbf{X}$ and $\mathbf{W}$ denote the input vector and weight vector, respectively. Then, the array output y is expressed as $y = \mathbf{X}^T\mathbf{W}^*$. The CM adaptive array works to eliminate the amplitude fluctuations of the array output signal due to the incidence of interferences. Therefore, the cost function to be minimized is represented as

$$Q = E[(|y|^2 - \sigma^2)^2] \tag{1}$$

where σ is the amplitude of the array output signal expected in the absence of any signal degradations[3],[4]. The minimization of Q is performed by the following algorithm based on the steepest descent method[3],[4]:

$$\mathbf{W}(m+1) = \mathbf{W}(m) - \mu\mathbf{X}(m)y^*(m)\{|y(m)|^2 - \sigma^2\} \tag{2}$$

where (m) denotes the iteration number of weight update and μ is the step size.

The directionally constrained CM (DCCM) adaptive array performs the above CM algorithm while maintaining a constant response to the desired direction and hence its guiding principle is formulated as follows:

$$\min_{\mathbf{W}} \left(Q = E[(|y|^2 - \sigma^2)^2]\right) \tag{3}$$

$$\text{subject to } \mathbf{C}^T\mathbf{W}^* = H \tag{4}$$

where $\mathbf{C}$ and H are the constraint vector and constrained response with regard to the desired direction, respectively. In this case, the optimization algorithm is expressed as

$$\mathbf{W}(m+1) = P[\mathbf{W}(m) - \mu\mathbf{X}(m)y^*(m)\{|y(m)|^2 - \sigma^2\}] + \mathbf{F} \tag{5}$$

$$P = U - \frac{1}{K}\mathbf{C}\mathbf{C}^\dagger \tag{6}$$

$$\mathbf{F} = \frac{H^*}{K}\mathbf{C} \tag{7}$$

where U is the identity matrix and $\mathbf{F}$ is the uniform excitation weight vector with the main beam directed to the desired signal.

It is noted here that the array response in the direction of the desired signal is doubly specified by σ and H. It is easily proved that σ and H are connected by $\sigma^2 = P_s|H|^2$ where P_s is the input power of desired signal, and thus we must predict P_s exactly for setting σ and H. To avoid this, we modify the algorithm of (5) by adopting σ^2 which is estimated in terms of the past $|y|^2$ every iteration once the value of H is specified. At m-th iteration, we use the following $\sigma^2(m)$ in place of σ^2 in (5):

$$\sigma^2(m) = (1-\alpha)\sigma^2(m-1) + \alpha|y(m-1)|^2 \tag{8}$$

$$(m = 1, 2, 3....)$$

where α is a real constant satisfying $0 \leq \alpha \leq 1$ and called a forgetting factor. $\sigma^2(0)$ and α in (8) are given beforehand. We name this system the modified DCCM adaptive array.

3. COMPUTER SIMULATION

Since these algorithms are nonlinear with respect to the array weights, the closed-form solutions of the optimum weights do not exist. Therefore, computer simulation experiments are carried out. The antenna is a four-element linear, equispaced array of isotropic elements with an element spacing of a half wavelength. We generate a QPSK signal, which is transmitted over two multipath channels. Table 1 shows the detailed radio environment.

We first consider the following three initial weight vectors for the conventional CM adaptive array: (a) $\mathbf{W}(0) = \mathbf{F}$, (b) $\mathbf{W}(0) = [1,0,0,0]^T \equiv \mathbf{M}_1$, and (c) $\mathbf{W}(0) = [0,1,0,0]^T \equiv \mathbf{M}_2$. Fig.1 shows the learning curves of output SINR (Signal-to-Interference-plus-Noise Ratio). It is quite obvious that the initial weight vector (a) provides the best transient performance. On the other hand, the vectors (b) and (c) suffer from the abrupt reduction of convergence rate around 800th iteration. Thus, the CM adaptive array requires the knowledge on the direction of the desired signal for fast convergence. This is similar to the performance of the LMS adaptive array shown in Ref.[5].

Next, we show the learning curves of the DCCM adaptive array with σ^2 fixed. Fig.2 is the simulation results where (a) $\sigma^2 = 2$, (b) $\sigma^2 = 1$, and (c) $\sigma^2 = 0.5$. The case (b) gives the best performance because the value of σ^2 is equal to $P_s|H|^2$. As seen in the cases (a) and (c), however, even the slight deviation of σ^2 from the optimum value of 1 causes serious degradation of SINR, which implies that the choice of σ^2 is very critical.

Finally, the transient characteristics of the modified DCCM adaptive array using the algorithm of (8) are shown in Fig.3 where (a) $\sigma^2(0) = 2, \alpha = 0.2$, and (b) $\sigma^2(0) = 0.5, \alpha = 0.2$. Both learning curves attain high SINR at the early iteration because the values of σ^2 asymptotically and rapidly converge to the optimum value.

4. CONCLUSION

This paper proposed the CM (constant modulus) adaptive array operating under a directional constraint in multipath environments. Although the conventional CM adaptive array has an advantage that it does not need the *a priori* knowledge on the direction of the desired signal, our computer simulation experiments showed that it also requires this knowledge to set the best initial weights for fast convergence of the optimization algorithm. This is quite similar to the characteristics of the LMS adaptive array. On the other hand, the directionally constrained CM (DCCM) adaptive array can perform faster convergence owing to the available information on the direction of the desired signal. We improved the DCCM adaptive array further and demonstrated its good transient performance by computer simulation.

REFERENCES

[1] K. Takao and N. Kikuma, "Tamed Adaptive Antenna Array," IEEE Trans. Antennas and Propagat., vol.AP-34, pp.388-394, Mar. 1986.

[2] K. Takao and N. Kikuma, "An Adaptive Array Utilizing an Adaptive Spatial Averaging Technique for Multipath Environments," IEEE Trans. Antennas and Propagat., vol.AP-35, pp.1389-1396, Dec. 1987.

[3] J. R. Treichler and B. G. Agee, "A New Approach to Multipath Correction of Constant Modulus Signals," IEEE Trans. Acoust. Speech and Signal Process., vol.ASSP-31, pp.459-472, April 1983.

[4] K. Takahara and K. Takao, "Adaptive Array for Multipath Environment," Paper of Technical Group of IEICE of Japan, AP87-16, 1987.

[5] N. Kikuma and K. Takao, "Effect of Initial Values of Adaptive Arrays," IEEE Trans. Aerospace Electronic Syst., vol.AES-22, pp.688-694, Nov. 1986.

Table 1 Input data used in computer simulation.

desired signal	angle of arrival	: $\theta_s = 0°$
	power	: $P_s = 1$
	carrier phase	: $\phi_s = 0°$
interference (multipath)	angle of arrival	: $\theta_i = 60°$
	power	: $P_i = 1$
	carrier phase	: $\phi_i = 0°$
	delay time	: $\tau = 0.2T$
thermal noise	power	: $P_n = 0.01$
constrained response		: $H = 1$

(T : symbol duration of QPSK signal)

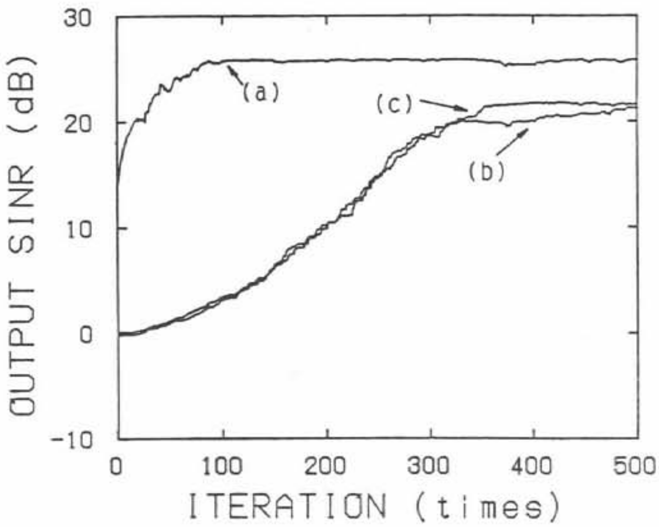

Fig.1
Learning curves of output SINR by the CM adaptive array with three different initial weights:
(a) $\mathbf{W}(0)=\mathbf{F}$
(b) $\mathbf{W}(0)=\mathbf{M}_1$
(c) $\mathbf{W}(0)=\mathbf{M}_2$.

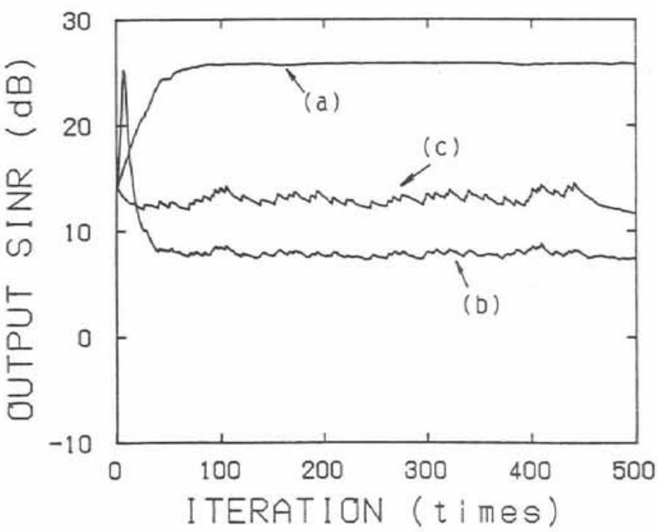

Fig.2
Learning curves of output SINR by the DCCM adaptive array using fixed values of σ^2 :
(a) $\sigma^2=2$
(b) $\sigma^2=1$
(c) $\sigma^2=0.5$.

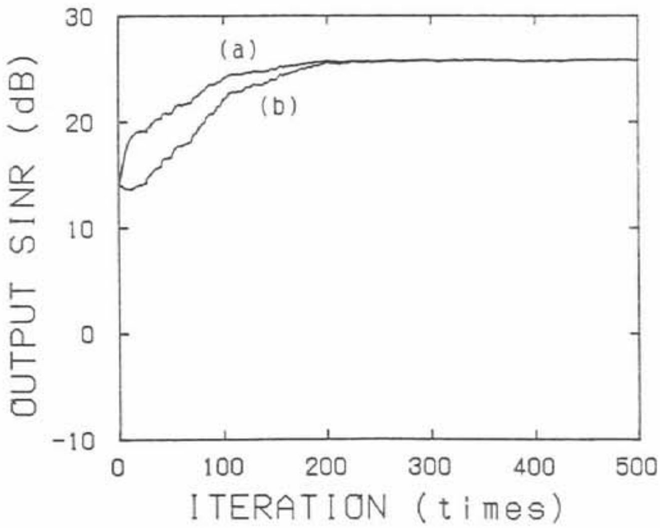

Fig.3
Learning curves of output SINR by the modified DCCM adaptive array with two different settings of $\sigma^2(0)$ and α :
(a) $\sigma^2(0)=2$, $\alpha=0.2$
(b) $\sigma^2(0)=0.5$, $\alpha=0.2$.