LATTICE BASED SPATIALLY AVERAGED ADAPTIVE ARRAY

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1. Introduction

When an adaptive array with main beam constraints, one of whose typical uses is a sidelobe canceller, receives interferences which are coherent with a desired signal, it rejects both the interferences and the desired signal[1]. This phenomenon degrades the performance of adaptive array systems and often arises due to multipath propagations and so forth.

To overcome this problem, we proposed a spatially averaged adaptive array[2,3] whose basic structure is equivalent to that of the multiple sidelobe canceller(MSLC) adaptive array presented by Applebaum and Chapman[4], and showed that it suppressed coherent interferences successfully. Apart from this, Shan and Kailath[5] proposed an adaptive array with directional constraints using "spatial smoothing" which is equivalent in the concept to the spatial average proposed by us and noted that it performed well for suppression of coherent interferences.

Recently, spatial lattice filter[6] was presented for high-resolution angle of arrival analysis by Scharman and Durrani, and it was shown that it could be applied to adaptive array beamforming, and had many advantages including suitability for a VLSI hardware implementation over conventional adaptive array systems. However, the coherent interferences can destroy its performance although it suppresses correlated interferences whose frequencies are close to that of the desired signal but not the same ones.

In this paper, we propose a new spatial lattice filter and its joint spatial lattice estimator whose behavior is equivalent to that of spatially averaged MSLC(SAMSLC) adaptive array and show computer simulation results regarding to its interference suppression characteristics.

2. Lattice based SAMSLC adaptive array

In this section, firstly we describe the interference rejection algorithm of the SAMSLC adaptive array, and secondly derive that of its lattice based version. The SAMSLC consists of several(N-M) blocks as shown in Fig.1 and the structure of each block is equivalent to that of the MSLC proposed by Applebaum and Chapman as expressed in Fig.2. Received signals $(z_1,..,z_N)$ can be obtained discretely at every time interval. Then, the error signal of the i th block $[e_i(k)]$ is defined as follows.

$$e_i(k)=Y_i(k)-W^T(k)X_i(k) \tag{1}$$

Where, $$Y_i(k)=\sum_{n=1}^{M+1} z_{i+n-1}(k) \tag{2}$$

$$X_i(k)=(z_{i+1}(k)-z_i(k),\dots,z_{i+M}(k)-z_{i+M-1}(k))^T, \tag{3}$$

$$W(k)=(w_1(k),w_2(k),\dots,w_M(k))^T. \tag{4}$$

(T denotes tranpose)

The total error power(TEP) from time 1 to t and from block 1 to N-M is

$$TEP=\sum_{i=1}^{N-M}\sum_{k=1}^{t} |e_i(k)|^2 \tag{5}$$

From [2,3], the optimum weight vector $W_{opt}(t)$ which minimizes TEP is given as follows.

$$W_{opt}(t)=[\sum_{i=1}^{N-M}\sum_{k=1}^{t} X_i^*(k)X_i^T(k)]^{-1}[\sum_{i=1}^{N-M}\sum_{k=1}^{t} X_i^*(k)Y_i(k)] \quad (6)$$

Where, * denotes complex conjugate.
Then, also from [2,3], Recursive Least Square(RLS) algorithm for the interference rejection of SAMSLC adaptive array is constructed by

$$W(t+1)=W(t)+P(t+1)[\sum_{i=1}^{N-M}(X_i^*(t+1)(Y_i(t+1)-W^T(t)X_i(t+1))] \quad (7)$$

where, $P(t+1)=[\prod_{i=1}^{N-M} (I-L_i(t+1)X_i^T(t+1))]P(t),$ (8)

$$L_i(t+1)=P_i(t)X_i^*(1+X_i^T(t+1)P_i(t)X_i^*(t+1)) \quad (9)$$

Next, we derive a lattice based interference rejection algolithm of SAMSLC adaptive array. We define $f_{m,i}(k)$ and $g_{m,i}(k)$ as the m th order forward and backward prediction errorrs for spatial series $x_i(k)$ respectively.

$$f_{m,i}(k)=A_m^T X_{m,i}(k) \quad (10)$$

$$g_{m,i}(k)=B_m^T X_{m,i}(k) \quad (11)$$

Where, $A_m=(1,a_{m,1},a_{m,2},\ldots,a_{m,m})^T,$ (12)

$$B_m=(b_{m,m},b_{m,m-1},\ldots,b_{m,1},1)^T, \quad (13)$$

$$X_{m,i}(k)=(x_i(k),x_{i-1}(k),\ldots\ldots,x_{i-m}(k))^T. \quad (14)$$

The spatio-temporally totaled foward and backward prediction error power can be expressed as TFPEP and TBPEP respectively.

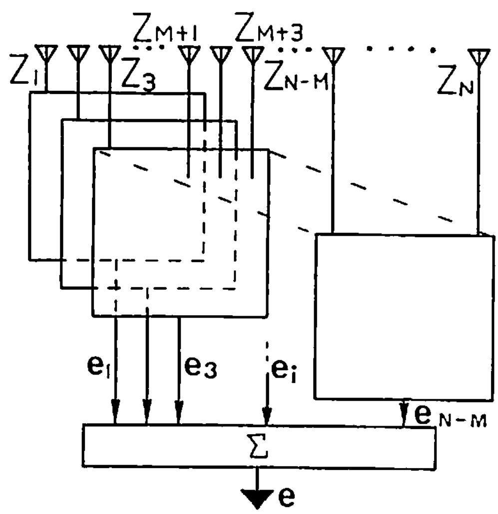


Fig.1 SAMSLC adaptive array

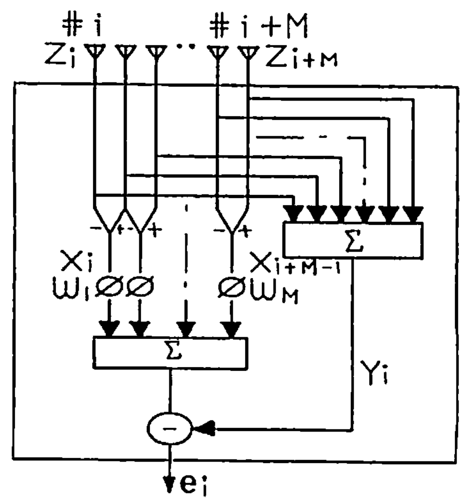


Fig.2 Structure of the i th block of SAMSLC adaptive array

$$TFPEP= \sum_{i=m+1}^{N-1} \sum_{k=1}^{t} |f_{m,i}(k)|^2 = A_m^T R_m(t) A_m^* \quad (15)$$

$$TBPEP= \sum_{i=m+1}^{N-1} \sum_{k=1}^{t} |g_{m,i}(k)|^2 = B_m^T R_m(t) B_m^* \quad (16)$$

$$\text{Where, } R_m(t)= \sum_{i=m+2}^{N-1} \sum_{k=1}^{t} X_{m,i}^*(k) X_{m,i}^T(k). \quad (17)$$

When we assume that the spatial covariance matrix $R_m(t)$ is spatially stationary, we can use Levinson-Durbin(L-D) method which computes efficiently A_m and B_m which minimize TFPEP and TBPEP as is the case with time domain lattice filter. Acoording to the L-D method, we can obtain the following relations.

$$A_{m+1}(t)= \begin{pmatrix} A_m(t) \\ 0 \end{pmatrix} + K_{m+1}(t) \begin{pmatrix} 0 \\ B_m(t) \end{pmatrix} \quad (18)$$

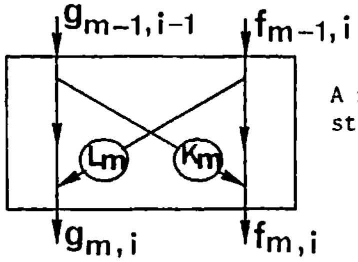
$$B_{m+1}(t)= \begin{pmatrix} 0 \\ B_m(t) \end{pmatrix} + L_{m+1}(t) \begin{pmatrix} A_m(t) \\ 0 \end{pmatrix} \quad (19)$$

$$f_{m+1,i}(t)=f_{m,i}(t)+K_{m+1}(t)g_{m,i-1}(t) \quad (20)$$

$$g_{m+1,i}(t)=g_{m,i-1}(t)+L_{m+1}(t)f_{m,i}(t) \quad (21)$$

$$K_{m+1}(t)=-\frac{\sum_{i=m+2}^{N-1} \sum_{k=1}^{t} g_{m,i-1}^*(k) f_{m,i}(k)}{\sum_{i=m+2}^{N-1} \sum_{k=1}^{t} g_{m,i-1}^*(k) g_{m,i-1}(k)} \quad (22)$$

$$L_{m+1}(t)=-\frac{\sum_{i=m+2}^{N-1} \sum_{k=1}^{t} f_{m,i}^*(k) g_{m,i-1}(k)}{\sum_{i=m+2}^{N-1} \sum_{k=1}^{t} f_{m,i}^*(k) f_{m,i}(k)} \quad (23)$$



A modular structure

Next, we extend the spatial lattice filter to have a joint spatial lattice estimator for adaptive array beamforming. The fundamental structure of lattice based SAMSLC adaptive array is equivalent to that of the conventional adaptive array as shown in Fig.1. The structure of the i th block can be illustrated in Fig.3. In Fig.3, weight $h_m(t)$ for $g_{m,i+m}(t)$ $(m=0,..,M-1)$ is considered to extract the desired signal from main antenna signal $Y_i(t)$. The time update algorithm for $h_m(t)$ can be expressed by

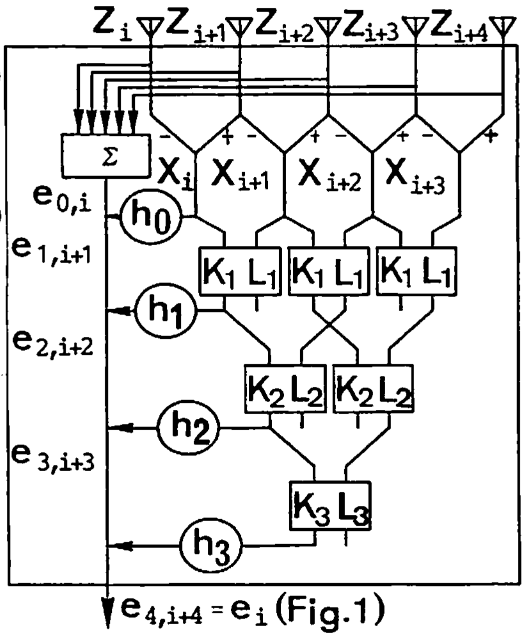


Fig.3 Structure of the i th block of lattice based SAMSLC

$$h_m(t+1)=h_m(t)+\Big[\sum_{i=1}^{N-M} (g_{m,i+m}^*(t+1)(e_{m,i+m}(t+1) - h_m(t)g_{m,i+m}(t+1)))\Big] \Big/ \Big[\sum_{i=1}^{N-M} [g_{m,i+m}^*(t+1)g_{m,i+m}(t+1))\Big]. \quad (24)$$

The desired signal is obtained as the error signal $e_{m,i+m}(t)$.

$$e_{m+1,i+m+1}(t)=e_{m,i+m}(t)-h_m(t)g_{m,i+m}(t) \quad [\, e_{M,i+M}(t)=e_i(t) \text{(in Fig.1)}] \quad (25)$$

$$[\, f_{0,i}(t)=g_{0,i}(t)=x_i(t), \quad e_{0,i}(t)=Y_i(t)= \sum_{n=1}^{M+1} z_{i+n-1}(t) \,]$$

3. The interference rejection characteristics.

Here, we show the comparison of interferece rejection results between coventional MSLC and lattce based SAMSLC. Fig.4(a) and Fig.4(b) show array pattern after adaptation of MSLC and lattice based SAMSLC respectively for non-coherent interferences. Fig.5(a) and Fig.5(b) illustrate coherent interference suppression results. From these figures, it is shown that MSLC suppresses only non-coherent interferences while lattice based SAMSLC suppresses both the non-coherent and the coherent interferences.

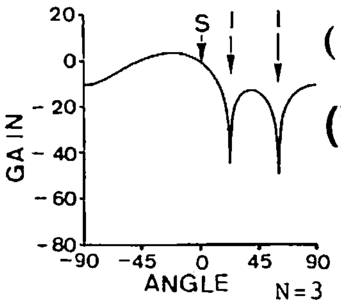


Fig.4(a) Conventional MSLC

(S:signal
I:interference)

(non-coherent
case)

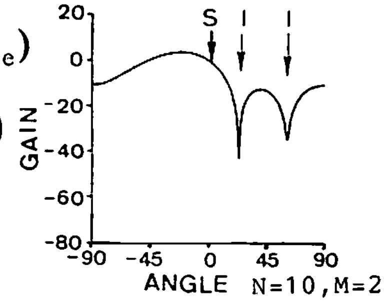


Fig.4(b) Lattice based SAMSLC

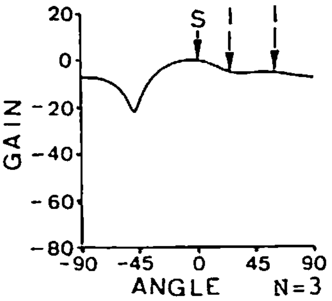


Fig.5(a) Conventional MSLC

(coherent
case)

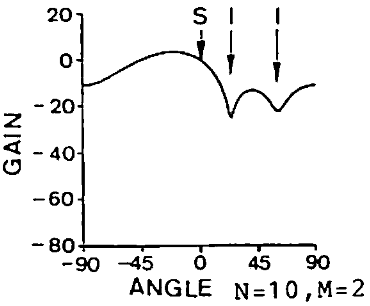


Fig.5(b) lattice based SAMSLC

4. Conclusion

Lattice based SAMSLC adaptive array is constructed. It efficiently computes parameters such as weights for adaptive array beamforming and it is found that lattice based SAMSLC suppresses both the coherent and non-coherent interferences.

References

[1]N.Kikuma and K.Takao: "The behahior of an adaptive array against coherent interference",TGAP83-20,IECE,Japan(1983-06)

[2]H.Watanabe and S.Nishimoto; "Charasteristics of correlated interference rejection using an adaptive antenna with spatial learning",TGSANE 83-54, IECE, JAPAN (1984-02)

[3]H.Watanabe and S.Nishimoto; "Correlated interference rejection characteristics of adaptive antenna with spatial learning" Proc. of ISNCR-84,TOKYO,JAPAN, pp.585-590(Oct.22-24,1984)

[4]S.P.Applebaum and D.J.Chapman; "Adaptive arrays with main beam constraints",IEEE Trans. Antennas Propag.,Vol.AP-15,pp.650-662(Sep.1976)

[5]T.J.Shan and T.Kailath: "New adaptive processor for coherent siganls and interferences" Proc. of IEEE ASSP conf. pp.33.5.1-33.5.4(Mar.1984)

[6]K.C.Sharman and T.S.Durrani: "Spatial lattice filter for high resolution spectral analysis of array data" IEE proc.F,No.3,pp.279-287 (Apr.1983)