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# A Novel Joint Combing Time-spatial Diversity Blind Equalization Algorithm

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*Abstract*— **According to the defects of constant modulus algorithm based on orthogonal wavelet transform (WT-CMA) ,and the inter-symbol Interference (ISI) caused by multi-path fading , a novel blind equalization algorithm is presented. In this proposed algorithm, FFT technique and overlapping retention algorithm are introduced firstly to realize WT-CMA in frequency domain (FWTCMA), which obtains a better performance and little computational complexity contrast with WT-CMA. Secondly, a new time-spatial structure is proposed which exploit the advantages of time diversity and spatial diversity with different combining modes to overcome the multi-path fading and the problem caused by the single mode effectively. Then, the presented structure is applied to the FWTCMA to get a novel joint combining time-spatial diversity blind equalization algorithm (JCTSD-FWTCMA). The simulation results show that the proposed algorithm has low Mean Square Error (MSE) and computational complexity, fast convergence rate.**

***Index Terms***— **orthogonal transform; constant modulus algorithm; time-spatial diversity; joint combining**

## I. INTRODUCTION

Inter-Symbol Interference (ISI) caused by multi-path fading and channel distortion in underwater acoustic is a key factor to reduce the communication quality [1]. And it can be overcome effectively by blind equalization which doesn't need training sequence. Constant Modulus Algorithm (CMA) has become classical algorithm because of the simple principle and low computational complexity. But the CMA has large Mean Square Error (MSE) and slow convergence rate. For overcoming the defects of CMA, wavelet transform is introduced to CMA at a larger computational cost [2-3]. Then LMS algorithm in frequency domain can obtain better performance and lower computational complexity than time domain by using cyclic convolution instead of liner convolution [4]. However, all these algorithms are focus on only one channel until diversity technique is employed [5-8]. It has obtained well results, but only a single kind of diversity technique and combing mode is used.

In this paper, frequency domain constant modulus algorithm based on wavelet transform (FWTCMA) is got firstly in single channel by using FFT technique and overlapping retention algorithm. Then a new structure of joint combing time-spatial diversity is proposed. In this structure, some different spatial blocks are employed to time diversity. The defects of multi-path fading can be reduced not only by the time diversity but also spatial diversity. In spatial block, FWTCMA is used to update the weight vectors of every branch and their output signals are combined as one of input of the time diversity combiner. then, the combiner combines the signals of every spatial block's output .Selective combining (SC) and maximal ratio combining (MRC) are chosen respectively as the combining modes of spatial blocks and time diversity to overcome the problem caused when the single mode is chosen. At last, a novel joint combining time-spatial diversity blind equalization algorithm (JCTSD-FWTCMA) is got.

## II. THE PROPOSED ALGORITHM

### A. *Constant Modulus Algorithm based on wavelet transform in frequency domain*

As we known, for obtaining good convergence performance, the ratio of maximum eigenvalue and minimal eigenvalue in input signal matrix has been reduce at the cost of larger computational complexity in WT-CMA . Frequency domain WT-CMA is obtain when FFT technique and overlapping retention algorithm is used to calculate the convolution. The structure is shown in Fig,1.

Where $\{a(n)\}$ is the channel input sequence; $\boldsymbol{c}(n)$ presents the impulse response vectors of every channel; $\{w(n)\}$ denotes an i.i.d.additive white Gaussian noise; $\boldsymbol{y}(n)$ and $\boldsymbol{r}(n)$ are the input signal and output signal of wavelet transform converter severally. $\boldsymbol{Q}$ is the wavelet transform matrix and is given by $\boldsymbol{Q}=[\boldsymbol{G}_0;\boldsymbol{G}_1\boldsymbol{H}_0;\boldsymbol{G}_2\boldsymbol{H}_1\boldsymbol{H}_0;\boldsymbol{G}_{J-1}\boldsymbol{G}_{J-2}\cdots\boldsymbol{H}_1\boldsymbol{H}_0\;;\boldsymbol{H}_{J-1}\boldsymbol{H}_{J-2}\cdots\boldsymbol{H}_1\boldsymbol{H}_0];$

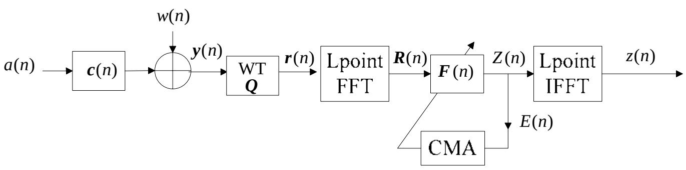



Fig.1 Structure of frequency domain constant modulus algorithm based on wavelet transform

where $\boldsymbol{H}_j$ and $\boldsymbol{G}_j$ are made of the coefficient of wavelet filter $h(n)$ and the coefficients of scale filters respectively. $\boldsymbol{F}(n)$ denotes the weight vector of equalizer in frequency domain and is given by $\boldsymbol{F}(n)=[F(n),F(n+1),\cdots,F(n+M_f-1)]$ ( $M_f$ is the length of equalizer); $\boldsymbol{R}(n)$ is the input signal of frequency domain equalizer. The signal after wavelet transform is

$$\boldsymbol{r}(n)=\boldsymbol{Q}\boldsymbol{y}(n). \qquad (1)$$

There is a $2L$ points sequence made up with $n$ th and $(n-1)$ th blocks of $\boldsymbol{r}(n)$ which is divided into some $L$ points sequences. At the same time , $L$ zeros are put after $\boldsymbol{f}(n)$ which is the weight vector of every blocks in time domain. When $n=1$, $L$ zeros are put around of $\boldsymbol{r}(1)$

$$\boldsymbol{R}(n)=\mathrm{FFT}\{r(nL-L),r(nL-L+1),\cdots r(nL-1)r(nL),r(nL+1)\cdots r(nL+L-1)] \qquad (2)$$

$$\boldsymbol{F}(n)=\mathrm{FFT}[\boldsymbol{f}^{\mathrm{T}}(n),0,0,\cdots,0] \qquad (3)$$

$$Z(n)=\boldsymbol{R}(n)\boldsymbol{F}(n) \qquad (4)$$

$$E(n)=Z(n)-R_F \qquad (5)$$

Where $R_F$ is the module of input signal; a normalization matrix is need when wavelet transform combine with CMA[2]. For obtaining the matrix $[\hat{\boldsymbol{R}}(n)]^{-1}$ ,we assume that

$$\boldsymbol{r}(n)=[r_{1,0}(n),r_{1,1}(n)\ \cdots\ r_{J,k_J}(n),s_{J,0}(n),\ \cdots\ s_{J,k_J}(n)]^T,$$

$$\begin{cases} r_{jk}(n)=\sum_i y\ (n-i)\varphi_{jk}(i) \\ s_{jk}(n)=\sum_i y\ (n-i)\phi_{jk}(i) \end{cases}. \qquad (6)$$

Where $\varphi_{jk}(i)$ and $\phi_{jk}(i)$ denote wavelet functions and scale functions. The normalization matrix is $[\hat{\boldsymbol{R}}(n)]^{-1}=$ $\mathrm{diag}\{[\sigma_{j,0}(n)]^2,[\sigma_{j,1}(n)]^2,\cdots,[\sigma_{J,k_J}(n)]^2,[\sigma_{J+1,0}(n)]^2,\cdots,[\sigma_{J+1,k_J}(n)]^2\}$ ; $[\sigma_{j,k_J}(n)]^2$ and $[\sigma_{j+1,k_J}(n)]^2$ are the average power estimate of $r_{j,k_J}(n)$ and $s_{j,k_J}(n)$ respectively, and updated by the following equations

$$[\hat{\sigma}_{j,k_J}(n+1)]^2=\beta[\hat{\sigma}_{j,k_J}(n)]^2 +(1-\beta)\,|\,r_{j,k_J}(n)\,|^2, \qquad (7a)$$

$$[\hat{\sigma}_{j+1,k_J}(n+1)]^2=\beta[\hat{\sigma}_{j+1,k_J}(n)]^2 +(1-\beta)\,|\,s_{j,k_J}(n)\,|^2. \qquad (7b)$$

On the basis of above equations, updating formula of weight vector is given by

$$F(n+1)=F(n) +2\mu\hat{\boldsymbol{R}}^{-1}(n)E(n)sign(Z(n))\boldsymbol{R}^*(n). \qquad (8)$$

*B. The structure of the proposed algorithm*

Time diversity technique sends the same signals repeatedly at the interval of a period which exceeds the coherence time; and spatial diversity sends them in different channels. Time-spatial diversity technique can be got when the both are used at the same time, the structure is shown in Fig.2.

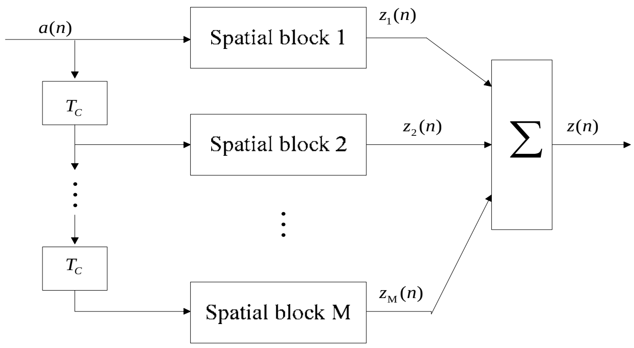



Fig..2 structure of time-spatial diversity

Where $T_c$ is time interval; $M$ is the time diversity number; $z_l(n)$ denotes the output signal of $l$ th spatial block $(l=1,2,\cdots M)$ ; $z(n)$ is the output of combiner. In Fig,2, the input signal $a(n)$ is sent in the same time interval ,and is transferred in different spatial blocks, the output of every spatial block will be combined in maximal ratio combining (MRC),and the results as the output of the whole system. In this paper, for overcoming the defect of single combing,in spatial blocks , the selective combing (SC) is chosen. The structure of $l$ th spatial block is shown in Fig,3.

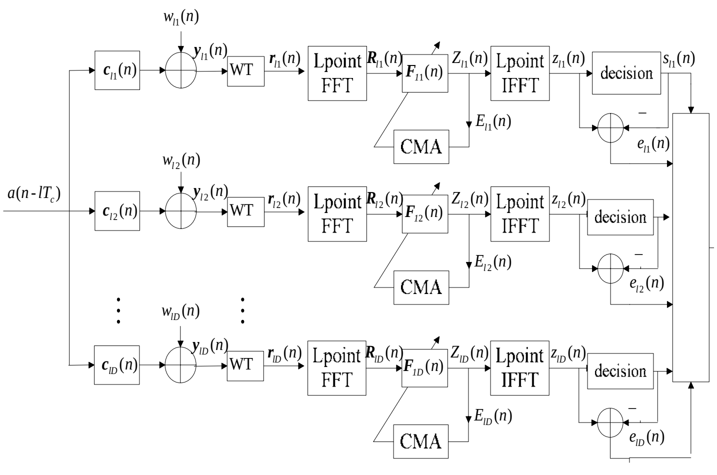



Fig..3 Structure of $l$ th spatial block

Fig.3shows that there are $D$ branches in $l$ th spatial block which FWTCMA is used to updated the weight vector. Every branch's output signals are be selective by selective logic, the branch which has the highest SNR is the output of this spatial block.

*C. The description of proposed algorithm*

In the structure of $l$ th spatial block, FWTCMA is used to update the weight vectors in every branch, the process of $i$ th branch 's weight vector in the $l$ th spatial block is

$$Z_{li}(n) = \boldsymbol{R}_{li}(n)\boldsymbol{F}_{li}(n), \tag{9}$$

$$E_{li}(n) = Z_{li}(n) - R_F, \tag{10}$$

$$\boldsymbol{F}_{li}(n+1) = \boldsymbol{F}_{li}(n),$$
$$+2\mu\hat{\boldsymbol{R}}_{li}^{-1}(n)E_{li}(n)sign(Z_{li}(n))\boldsymbol{R}_{li}^{*}(n). \tag{11}$$

Where $Z_{li}(n)$ is the FFT transform of $z_{li}(n)$ , $s_{li}(n)$ is the output of decision, the arrange measuring error of transporting $j$ th character is

$$e_{li}(n-j) = z_{li}(n-j) - s_{li}(n-j). \tag{12}$$

Then when $N_B$ characters are transported in this branch, the measuring error is

$$\bar{E}_{li}(n) = \frac{1}{N_B}\left(\sum_{j=0}^{N_B-1} |\, e_{li}(k-j)\,|\right). \tag{13}$$

All branches is compared by calculating the $\bar{E}_{li}(n)$ ,the branch which has the smallest $\bar{E}_{li}(n)$ is selectived as the output of $l$ th spatial block. All branch signals are combined at the same process in the spatial blocks The output signals of every spatial blocks are combined by the combiner in Fig.2.In this combiner, Maximal ratio combining (MRC) is chosen to overcome the defect of single combining, then the output of combiner in Fig.2 is

$$z(n) = \sum_{l=1}^{D} \frac{A_l}{\sigma_l^2} z_l(n). \tag{14}$$

Where $A_l$ and $\sigma_l^2$ denote the amplitude and noise variance of the output signal of $l$ th spatial block, respectively. (9)-(14) are the whole process of the novel algorithm.

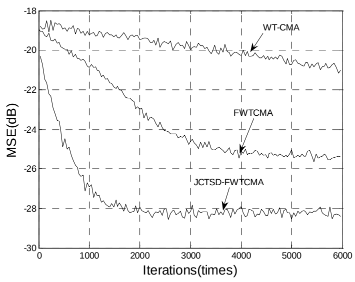
## III. ANALY SIS OF COMPUTATIONAL COMPLEXITY

The computational complexity of single branch is discussed firstly. We assume the wavelet transform matrix $\boldsymbol{Q}$ which is sparse has $L$ nonzero elements in every row, there are $LN$ and $L^2$ multiplications to complete the wavelet transform and linear convolution respectively .So we need $LN + L^2$ multiplications in WT-CMA. In the FWTCMA, the cyclic convolution is used instead of linear convolution, there are three times $L$ points FFT and two times $2L$ points complex multiplications. For the real input, half computational complexity can be reduced because of the symmetry, at the same time, $2L$ points FFT is realized by $L$ points FFT and $L$ complex multiplications.

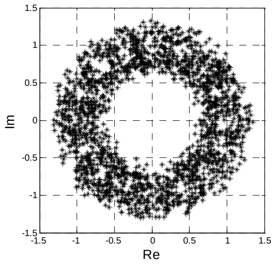
So $3L\log_2(L/2)$ $+4L + LN$ multiplications are needed to complete the FWTCMA, when one complex multiplication equal four real multiplications. The computational complexity is reduced which can be shown in the following equation $\Delta = LN + L^2 - 3L\log_2(L/2)$ $+4L + LN$ ,if $L = 32$ ,then $\Delta = 786$ .And in the whole algorithm, there are $786DM$ multiplications can be reduced.

## IV. SIMULATIONS

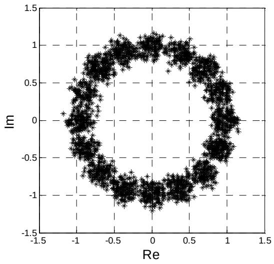
For testing the performance of the proposed TSD-FWTCMA, 16PSK data symbols were transmitted through four underwater acoustics channels if we assume $M = D = 2$, there are two spatial blocks and there are two branches in every spatial block. $\boldsymbol{c}_1$=[0.9656 -0.0906 0.0578 0.2368] and $\boldsymbol{c}_2$= [0.8264 -0.1653 0.1653] were the first spatial block channels; $\boldsymbol{c}_3$=[0.35 0 0 1] and $\boldsymbol{c}_4$=[0.2 0.5 1 -0.1] were the second spatial block channels. The SNR was set to 20dB, all the equalizers had 32 taps and their center taps were initialized to 1.Simulations were carried out via employing the DB2,the wavelet storey is 2,the initial power was 4; $\beta = 0.999$ ; the step-size of WT-CMA was $0.00155$; the step-size of FWT-CMA was $0.015088$; in the JCTSD-FWTCMA, the step-sizes of first spatial block were $0.007$ and $0.0073$, the step-sizes of second spatial block were $0.15$ and $0.15$ ;the results of Monte Carlo 1500 were shown in Fig,4.



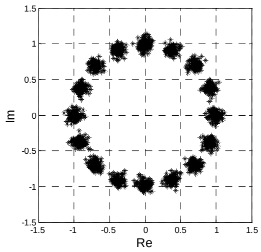

(a) The MSE curves of algorithms



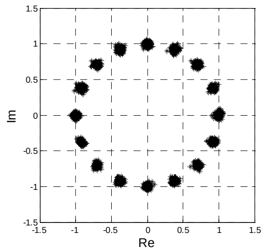

(b) Equalizer input




(c) Equalizer signals with WT-CMA




(d) Equalizer signals with FWTCMA




(e) Equalizer signals with JCTSD-FWTCMA

Fig.4 simulation results

Fig.4(a)shows that the convergence rate of JCTSD-FWTCMA performs an improvement of about 4500 steps ,2500 steps comparison with the WT-CMA and FWTCMA respectively. The MSE of JCTSD-FWTCMA performs a drop of about of 8dB and 3.5dB comparison with the WT-CMA and FWTCMA respectively. From Fig.4(c.d.e) , the FWTCMA' s constellations are clearer and more focus than WT-CMA's, and the JCTSD-FWTCMA' s are clearest and most focus.

## V. CONCLUSIONS

According to the defects of multi-path and Constant Modulus Algorithm based on wavelet transform (WT-CMA) in signal channel A novel Joint combing time-spatial diversity blind equalization algorithm(JCTSD-FWTCMA) is proposed. The proposed algorithm use the frequency method to reduce the computational complexity and obtain good performance, construct joint combining time-spatial diversity to overcome the defect of multi-path. The simulation results with underwater acoustics channel show that the proposed JCTSD-FWTCMA has favorable performance.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