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Fading Noise Reduction Effect Through the Short Time DFT Compander

Short Time DFTコンパンダのフェージング雑音抑圧効果

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ABSTRACT *Signals transmitted over poor radio channels are interfered by fading noise to be degraded in speech quality. The short time DFT (ST DFT) compander has successfully excluded envelope detection owing to employing concept of instantaneous spectrum instead of employing approximated AM demodulation in realizing the envelope detectors. This ST DFT compander is able to reduce fading noise to improve speech quality over poor radio channels without any distortions. The ST DFT compander is discussed in this paper to optimize their structures and is also discussed to be sufficient in noise reduction both from theoretical analysis and computer simulations.*

1. INTRODUCTION

It becomes to be eager for effective utilization of radio frequency resources through both narrowing spectrum occupancy and reducing transmission power. Unfortunately, narrowing bandwidth in angular modulation loses the merits of low noise during wide band amplifiers, and saving transmission power introduces demerits of being suffered from thermal or fading noise. Therefore, such noise reduction facilities as compander or diversity receiving are inevitable in narrow band communication systems for preventing frequency resources from exhausting.

Companding is so well known as a technique for improving the signal to noise ratio (SNR) over poor radio channels. Many investigations are keenly studied on realizing the companders. However, conventional syllabic companders have been concerned with approximation in the way of AM demodulation to estimate signal envelope component with certain intermodulation error between input signals and their envelopes. An exact compander based on the ST DFT was successfully realized with employing instantaneous spectrum to exclude envelope detection to be almost free from any distortions.[1]

However, the ST DFT compander is suffered from the great deal of computation. A new optimizing structure of the ST DFT compander is proposed with introducing the discrete circular correlation to save great deal of computing power.

The fading noise not only causes such signal dispersion as intersymbol interference, but also causes severe damages in received SNR. The ST DFT compander gives a nonlinear op-

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eration of companding the input signal transmitted through the fading channel in order to improve speech quality based on the concept of instantaneous spectrum.

2. THE ST DFT COMPANDER AND ITS OPTIMIZATION

2.1 Principle of the ST DFT Compander

Let $x(n)$ represent samples of a speech signal, $\phi_k(n)$ is the k_{th} spectrum component of its instantaneous spectrum at sampling time n. Every spectrum component $\phi_k(n)$ is defined by the ST DFT as following,

$$\phi_k(n) = \sum_{r=-\infty}^{\infty} x(r)h(n-r)W_N^{-rk} \quad (1)$$

where, $W_N^{-rk} = exp\{-j(2\pi rk/N)\}$ integer k is $0 \leq k < N$; W_N^{-rk} is the same operator defined in the existing DFT; $x(r)$ is sampled input data at sampling time r; $h(*)$ is a significant window function defined by

$$h(p) = \begin{cases} 1, & if\, p=0 \\ 0, & if\, p=2Nu,\ u\ is\ nonzero\ integer \end{cases} \quad (2)$$

For example, a N frame length Nyquist window function truncated with $2L$ frame number $h(p)$,

$$h(p) = sin(p\pi/N)/(p\pi/N),\ -LN \leq p \leq LN \quad (3)$$

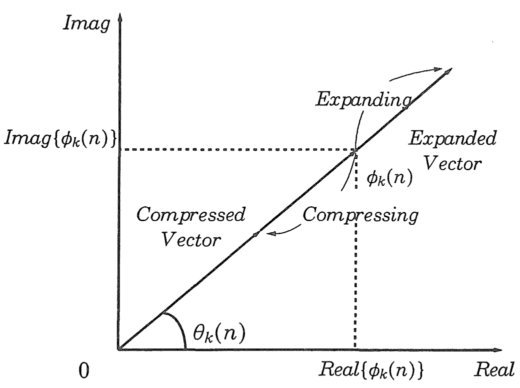


Fig.1 Companding the instantenious spectrum component on the phase plane.

may be employed as the window function in the ST DFT.

The functions of companding are performed on the phase plane via such operations as multiplying and dividing each vector of the instantaneous spectrum components in proportion to its absolute value. Let the k_{th} instantaneous spectrum component $\phi_k(n)$be

$$\phi_k(n) = |\phi_k(n)|e^{j\theta_k(n)} \quad (4)$$

The compressed/expanded instantaneous spectrum component $\tilde{\phi}_k(n)$is given by

$$\tilde{\phi}_k(n) = \left|\tilde{\phi}_k(n)\right|^{\alpha} e^{j\theta_k(n)} \quad (5)$$

where α is set to be 0.5 for compressor, and to be 2 for expander.

The companded output signals $y(n)$as given by

$$y(n) = \frac{1}{N}\sum_{k=0}^{N-1} \tilde{\phi}_k(n)W_N^{-rk} \quad (6)$$

It's obviously seen in eq.6 that the ST DFT compander is released from detecting the envelopes owing to employing instantaneous spectrum.

2.2 Optimizing Structure of the ST DFT Compander

It is shown in eq.1 that the instantaneous spectrum $\phi_k(n)$ is different from the form of the DFT and, therefore, can not be computed directly in following to the FFT algorithm. However, modulo structure is deduced from the ST DFT by setting variables $r = n+s$,and $s = lN+m$,

$$\phi_k(n) = \sum_{s=-\infty}^{\infty} x(n+s)h(-s)W_N^{-(n+s)k}$$

$$= \sum_{l=-\infty}^{\infty}\sum_{m=0}^{N-1} x(n+lN+m) \cdot h(-lN-m)W_N^{-(n+lN+m)k}$$

Interchanging the orders of summation ,

we obtain

$$\phi_k(n) = W_N^{-nk} \sum_{m=0}^{N-1} \widetilde{x_m}(n) W_N^{-mk} \quad (7)$$

where,

$$\widetilde{x_m}(n) = \sum_{l=-\infty}^{\infty} x(n+lN+m)h(-lN-m) \quad (8)$$

It gives convenient modifications for $\phi_k(n)$ that the DFT of the N - point (in m) sequence $\widetilde{x_m}(n)$ for fixed n is employed as in eq.7, which also allows introducing the FFT algorithm once $\widetilde{x_m}(n)$ has been formed.[2]

However, eq.8, which is defined by a kind of convolution, is also necessary to introduce the FFT algorithm. Equation 8 requires a great deal of computing power. Therefore,. it becomes to be important to design a high speed algorithm for computing eq.8.

Since $h(*)$ is an N frame length window function truncated with $2L$ frame number, the summation of eq.8 is limited into finite determined by $2LN$ in practice. Equation 8 is modified as

$$\widetilde{x_m}(n) = \sum_{l=-L}^{L-1} x(n+lN+m)h(-lN-m) \quad (9)$$

We introduce the following sub - sequences;

$$\begin{cases} h_m(l) = h(-lN-m) \\ x_{n+m}(l) = x(n+lN+m) \end{cases} \quad (10)$$

here,

$0 \le m \le N-1$,
$-L \le l \le L-1$,
$-LN \le n \le LN-1$.

Supposing the length of $x(r)$ to be $2LN$, which is the same to the length of $h(*)$, we define:

$$x(r) = \begin{cases} x(r+2LN), & r < -LN \\ x(r-2LN), & r > LN-1 \end{cases} \quad (11)$$

Then, $x_{pN+m}(l)$ can be recognized as the circular left - shift of $x_m(l)$.
Substituting eq.10 and $k = l + L$ into eq.9, it gives

$$\widetilde{x_m}(n) = \sum_{l=-L}^{L-1} x_{n+m}(l)h_m(l)$$
$$= \sum_{k=0}^{2L-1} x_{n+m}(k)h_m(k) \quad (12)$$

where, $h_m(k) = h[(L-k)N-m]$

$$x_{n+m}(k) = x[n+(k-L)+m] \qquad 0 \le k \le 2L-1$$

Setting the variable $n = pN + n'$

$$\widetilde{x_m}(pN+n') = \sum_{k=0}^{2L-1} x_{pN+n'+m}(k)h_m(k) \quad (13)$$

Then, $\widetilde{x_m}(pN+n')$ is recognized as the discrete circular correlation with p increase from $-L$ to $(L-1)$ for fixed n' and m. Therefore, the Discrete Circular Correlation Theorem can be employed for eq.13.

The DFT of $x_{-LN+n'+m}(k)$ and $h_m(k)$ are defined as;

$$X_{-LN+n'+m}(U) = F[x_{-LN+n'+m}(k)]$$
$$= \sum_{k=0}^{2L-1} x_{-LN+n'+m}(k)W_{2L}^{-Uk}$$

$$H_m(U) = F[h_m(k)] = \sum_{k=0}^{2L-1} h_m(k)W_{2L}^{-Uk} \quad (14)$$

where, $0 \le U,\ k \le 2L-1,\ \ 0 \le n',\ m \le N-1$.
Then,

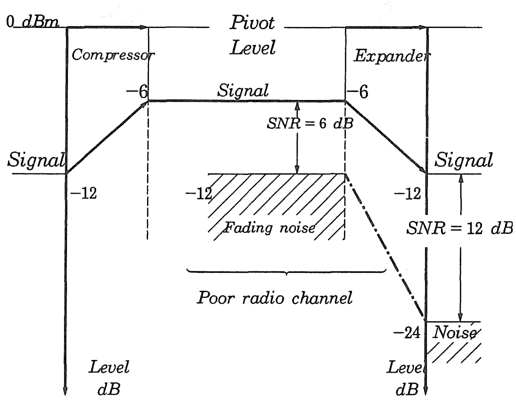


Fig.2 Level diagram over poor radio channel.

$$\widetilde{x_m}[(k-L)N+n'] = F^{-1}[X_{-LN+n'+m}(U)H_m^*(U)]$$

$$= (1/2L)\sum_{U=0}^{2L-1}[X_{-LN+n'+m}(U)H_m^*(U)]W_{2L}^{Uk} \quad (15)$$

Equation 15 shows clearly that the optimizing structure is introduced into the ST DFT compander based on the FFT algorithm in order to save great deal of computing power.

3. FADING NOISE REDUCTION EFFECT

3.1 Principle of Noise Reduction

In the ST DFT compander, input signal $x(r)$ is at first analyzed by ST DFT to yield instantaneous spectrum $\{\phi_k(n)\}$, as shown in eq.1. Secondly, every component of the instantaneous spectrum are dividing/multipling by prior amount to get compressed/expanded spectrum $\{\widetilde{\phi_k}(n)\}$, as shown in eq.5. The real part $\widetilde{a_k}(n)$ or imaginary part $\widetilde{b_k}(n)$ of compressed/expanded instantaneous spectrum component $\widetilde{\phi_k}(n)$is given as following

$$\widetilde{a_k}(n) = |\ \phi\ |^{\alpha-1} a_k(n)$$

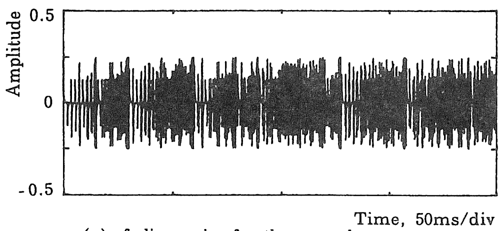
$$\widetilde{b_k}(n) = |\ \phi_k(n)\ |^{\alpha-1} b_k(n) \quad (16)$$

Here, α =0.5 for compressing, α =2 for expanding. On the frequency domain, every component is illustrated in fig.1 .

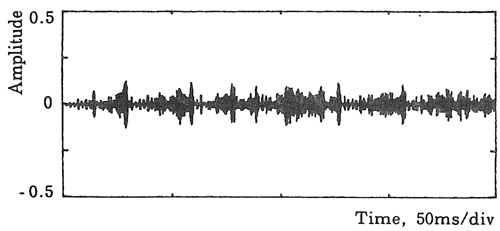
The output signal $y(n)$ is finally synthesized through ST DFT from compressed/expanded spectrum, as shown in eq.6. The nonlinear operation of expanding input signals is able to recover the degraded speech quality by twice in the meaning of decibel as shown in level diagram of fig.2 .

3.2 Simulation of Noise Reduction Effect

As discussed previously,the ST DFT companders are able to be used to reduce fading noise to improve the speech quality over poor channels with emphasis on employing concept of instantaneous spectrum to detect envelopes. All computer simulation of noise reduction effect via the ST DFT compander are performed on the supercomputer CRAY X-MP/14se at AIT. The window function frame number 2L is set to be 8 and frame length N is set to be 32 . The sampling frequency is set to be 8 KHZ.

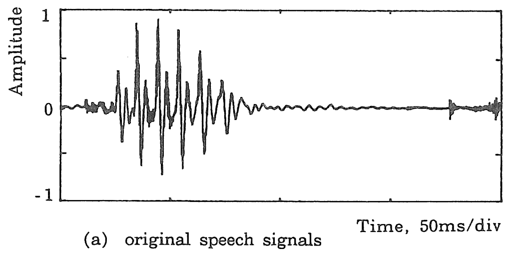


(a) fading noise for the expander

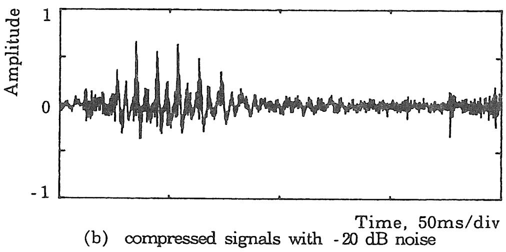


(b) expanded fading noise

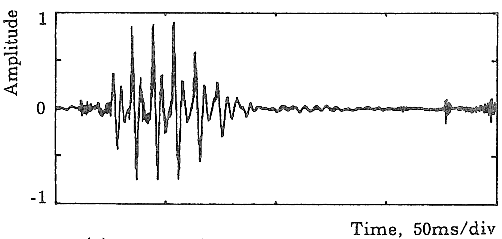
Fig.3 Noise reduction effect over silent duration.



(a) original speech signals



(b) compressed signals with -20 dB noise



(c) recovered signals

Fig.4 Noise reduction efferct over phonetic duration.

Noise Reduction Effect over Silent Duration

The fading noise for the expander is expanded as shown in fig.3(a) by 1 to 2 in decibel meanings. The expanded noise is shown in fig.3(b). The simulation shows that the ST DFT compander can efficiently suppress the fading noise over silent duration.

Noise Reduction Effect over Phonetic Duration

Figure 4(a) shows the signals over the phonetic duration before companding in the ST DFT compressor. Figure 4(b) shows transmitted signals damaged with -20 dBrms noise observed at the receiving site before expanding. Expanded signals are sufficiently recovered as shown in fig.4(c) via the ST DFT expander from the interfered noise.

4. CONCLUSION

The optimizing structure has been discussed in order to save computing power in the ST DFT compander. The ST DFT compander is shown to be sufficient in noise reduction both from theoretical analysis and computer simulation. Further studies on suppressing the multiplicative fading noise with the ST DFT compander will make the ST DFT companders more useful.

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