

DISPERSIVE EFFECT CORRECTION FOR ULTRA SHORT IMPULSE SIGNALS USING JOINT TIME-FREQUENCY TRANSFORMS

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The Joint Time-Frequency Transforms (JTFT) are employed to identify the time-frequency distribution of dispersed ultra short impulse signals transmitted through unknown propagation channels in the presence of noise. The channel dispersive effect can be corrected by pre-distorting the transmitted signals or using matched filter at receiver from the estimated time-frequency. Simulation results show both Short Time Fourier Transform (STFT) and Adaptive Local Cosine Transform (ALCT) are effective to correct the dispersive effects for ultra-short impulse signals.

1. Introduction

Ultra-short impulse signals, which possess ultra-wide bandwidth, have been widely used in the wireless communication systems and impulse radars for ground penetration and target identification. Because the system transmits pulses of very short duration on the order of a nanosecond, the signal contains frequencies ranging from near-DC to a few GHz. If the impulse signals are transmitted through a dispersive medium such as the ionosphere, there are usually different unknown time delays at the receivers for the different frequency components in the signal. Hence, to detect the dispersed signal from noise we need an effective time-frequency analysis algorithm to determine the time-frequency distribution of the received signal. Joint time-frequency transform (JTFT) is a useful tool for representing and analyzing time-frequency distribution of wideband signals [1]. The short-time Fourier transform (STFT), employing a fixed local time window size as the analysis window, is the most basic JTFT method [2]. For time-varying wideband signals, usually it is impossible to find an optimal window size to efficiently represent the entire signal using the STFT. The adaptive local cosine transform (ALCT) recently has been proposed for adaptive time-frequency analysis [3, 4]. It uses multi-scale basis functions and their time-shift versions to represent time-varying signals. Since time-varying signals have different frequency characteristics at different time locations and over different durations, the ALCT is well suited for analyzing such signals. One typical scenario requiring the detection of noisy time-varying signals is in receiving ultra-wideband

signals after propagation through a dispersive channel. An example is the recently proposed ultra-short wideband impulse radio system [5]. If the impulse radio signals are transmitted through a dispersive medium such as the ionosphere, there are usually different unknown time delays at the receivers for the different frequency components in the signal. Hence, to detect the dispersed signal from noise we need an effective time-frequency analysis algorithm to determine the time-frequency distribution of the received signal. Due to the time-varying feature of the dispersed wideband signal, we expect JTFT to be effective in estimating the signal time-frequency characteristics and detecting the subsequently arrived dispersed pulses from noise by correlation processing. In this paper, ALCT algorithm is briefly described (readers are referred to [1, 2] about STFT), then the effectiveness of JTFT is demonstrated by correcting the noisy dispersed wideband impulse signals using ALCT and STFT.

2. Adaptive Local Cosine Transform (ALCT)

A local cosine basis of $L^2(\mathfrak{R})$ is defined from a cosine-IV basis of $L^2[0,1]$ by multiplying a translation and dilation of each vector with a smooth window $g_p(t)$ [3]. An orthonormal local cosine basis of $L^2(\mathfrak{R})$ is defined as follows:

$$\{g_{p,k}(t) = g_p(t) \sqrt{\frac{2}{l_p}} \cos\left[\pi\left(k + \frac{1}{2}\right)\frac{t - a_p}{l_p}\right]\}_{k \in \mathbb{N}, p \in \mathbb{Z}}, \quad (1)$$

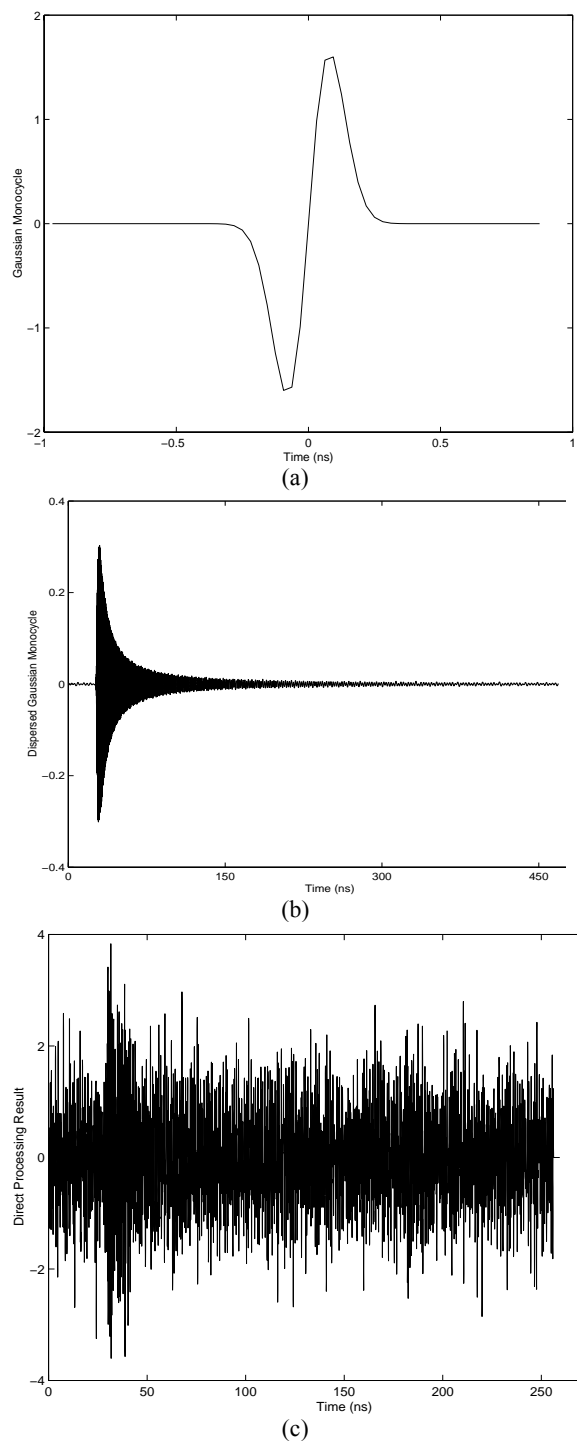


Fig. 1.
 (a) The Gaussian monocycle used in impulse radio.
 (b) The dispersed Gaussian monocycle after propagation through a dispersive medium.
 (c) The direct correlation processing result

where p is an index of the time interval, k is a frequency index, and a_p and l_p denote respectively the position and support of the window g_p . The win-

dows are usually overlapping, and need to satisfy symmetry and quadrature properties.

The adaptive local cosine transform tries to find a group of window parameters $\{a_p, l_p\}$ for the basis in (1) to represent a signal most efficiently. To quickly search for the best local cosine basis for a signal, we restrict the segmentation of the time axis to the intervals of dyadic sizes, and thus the fast algorithm proposed in [6] to search for the best wavelet packet basis can be used to search for the best local cosine basis using a binary tree. Suppose a signal exists in the interval $[0, T]$, and the maximum level of the decomposition in the tree is J , the length of the equally divided intervals on level j is $2^{-j}T$ ($0 \leq j \leq J$). A fast algorithm is available to compute the decompositions on the level j from the results on the level $j - 1$. With an additive cost function, the same pruning algorithm used in [6, 7] is applicable to finding the best local cosine basis from a fully decomposed tree. Usually the entropy function or the energy concentration function is defined as the cost function to measure the efficiency (sparsity) of the transformed signal. The total computational cost for the best local cosine basis search and transform is about $O(Jn \log_2 N)$. Readers are referred to [6, 7] for a detailed description of the search algorithm.

3. Detection and Estimation of Noisy, Dispersive Signals Using ALCT

A Gaussian monocycle used in impulse radio, as shown in Fig. 1(a), is ultra short wideband impulse. It is transmitted through a distance of D in the ionosphere. The phase delay for the signal component at frequency f is given by:

$$\phi(f) = 2\pi f \frac{D}{c} \sqrt{1 - \left(\frac{f_p}{f}\right)^2}, \quad (2)$$

where c is the speed of light in free space and f_p is the plasma frequency of the ionosphere and is dependent on the electron density. The instantaneous group delay is then given by

$$\tau_d = \frac{1}{2\pi} \frac{d\phi}{df} = \frac{D}{c \sqrt{1 - \left(\frac{f_p}{f}\right)^2}}. \quad (3)$$

The above equation indicates that the time delays for different frequency components are different and the time-frequency distribution of the received signal through the ionosphere is a non-linear curve. Hence, a time-frequency analysis tool is necessary to effectively identify such a signal. Fig. 1(b) shows the dis-

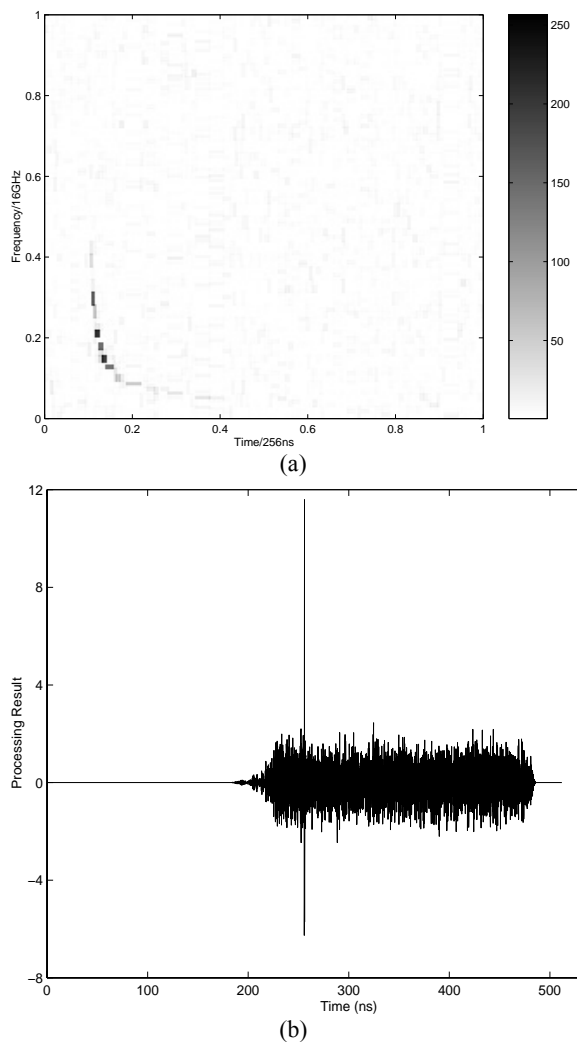


Fig. 2.
 (a) The time-frequency distribution of the dispersed signal shown in Fig. 1(c) using the adaptive local cosine transform (ALCT).
 (b) The correlation processing result using the recovered template using ALCT

persed signal after the Gaussian monocycle in Fig. 1(a) travels 300 km through ionosphere with $f_p = 9$ MHz. Usually the received signals are corrupted by additive white Gaussian noise (AWGN) with the transmission. For the dispersed received signal with AWGN with a signal-to-noise ratio (SNR) of -3.5 dB, the direct correlation processing result is shown in Fig. 1(c). It is observed that the dispersive effect leads to the loss of the high range resolution and the received signal is almost undetectable in the noise due to significant SNR loss from the dispersion. In order to correct the dispersive effect, the time delay vs. frequency characteristics in (3) is needed for the propagation channel. Since the original signal has zero time-delay for all frequencies, the joint time-

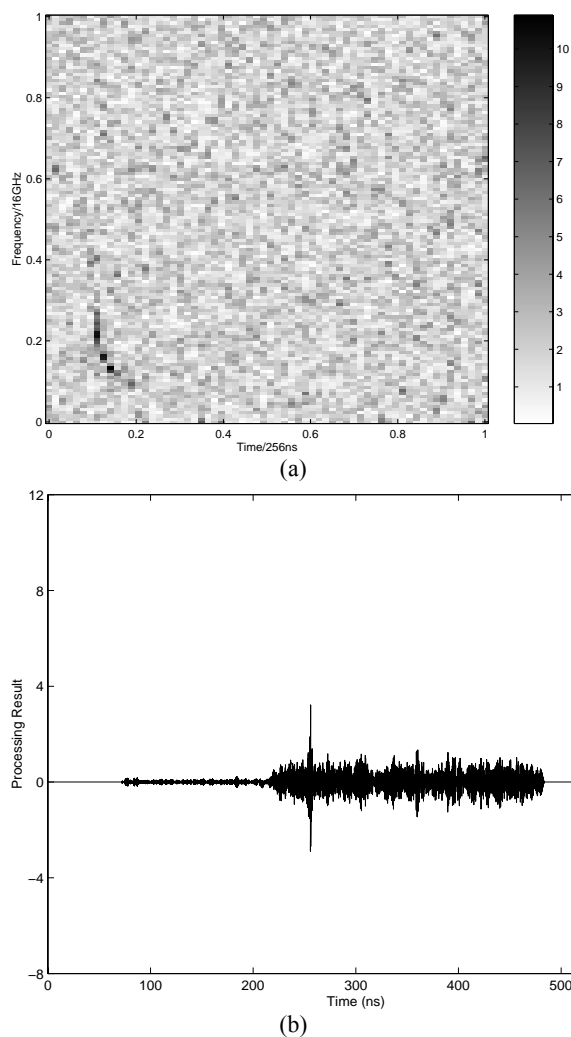


Fig. 3.
 (a) The time-frequency distribution of the dispersed signal shown in Fig. 1(c) using the STFT.
 (b) The correlation processing result using the recovered template using STFT

frequency trajectory of the received signal is exactly the group delay vs. frequency characteristic in (3).

With JTFT processing, the energy of the dispersed signal is automatically concentrated in the time-frequency domain. At the same time, the transformed AWGN remains un-correlated. Therefore the SNR is improved in the JTF domain. To recover the signal from noise we need to apply a hard threshold to the transformed signal. A time-domain template is formed by inverse-transforming the signal in JTFT domain for subsequent correlation processing to correct for the channel dispersion. Fig. 2(a) is the ALCT processing result of the noise-corrupted received signal shown in Fig. 1(c). Fig. 2(b) is the correlation processing result with a dispersed pulse using the template recovered through ALCT. From Fig. 1(c) to

Fig. 2(b), one finds that the processing leads to a much more detectable signal through the matched filtering processing. The similar processing results of the same signal in Fig. 1(c) using the STFT are shown in Figs. 3(a,b). It is observed that the resulting SNR is higher by using the ALCT processing than using STFT because of the adaptive window sizes used along the time axis.

4. Conclusions

Simulation results show that the dispersed ultra-wideband signals are completely buried in noise at the receiver without any time-frequency processing, yet can be reliably detected and restored with either STFT or ALCT processing. However the Signal-to-Noise Ratio (SNR) achieved is much higher through ALCT processing. Furthermore, based on the time-frequency characteristics found using ALCT processing, it is also possible to transmit pre-distorted ultra-wideband pulse signals to completely compensate for the channel dispersive effect. Furthermore, based on the time-frequency characteristics found using JTFT processing, it is also possible to transmit pre-distorted signals to completely compensate the channel dispersive effect.

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КОРРЕКЦИЯ ДИСПЕРСИОННОГО ЭФФЕКТА ДЛЯ УЛЬТРАКОРОТКИХ ИМПУЛЬСНЫХ СИГНАЛОВ С ПОМОЩЬЮ СОВМЕСТНОГО ЧАСТОТНО-ВРЕМЕННОГО ПРЕОБРАЗОВАНИЯ

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Совместное частотно-временное преобразование (JTFT) используется для идентификации частотно-временного распределения диспергированных ультракотких импульсных сигналов, прошедших через неизвестные каналы распространения в присутствии шума. Дисперсионный эффект канала можно откорректировать предварительным искажением передаваемого сигнала или использованием согласованного фильтра на приемнике. Результаты моделирования показывают, что и коротковременное преобразование Фурье (STFT), и адаптивное локальное косинусное преобразование являются эффективными для коррекции эффектов дисперсии ультракотких импульсных сигналов.

КОРЕКЦІЯ ДИСПЕРСІЙНОГО ЕФЕКТУ ДЛЯ УЛЬТРАКОРОТКИХ ІМПУЛЬСНИХ СИГНАЛІВ ЗА ДОПОМОГОЮ СПІЛЬНОГО ЧАСТОТНО-ЧАСОВОГО ПЕРЕТВОРЕННЯ

Хай Денг

Спільне частотно-часове перетворення (JTFT) використовується для ідентифікації частотно-часового розподілу диспергованих ультракотких імпульсних сигналів, що пройшли крізь невідомі канали розповсюдження у присутності шуму. Дисперсійний ефект каналу може бути відкоректований попереднім спотворенням сигналу, що передається, або застосуванням узгодженого фільтра на вході приймача. Результати моделювання вказують, що і короткочасове перетворення Фур'є (STFT), і адаптивне локальне косинусне перетворення є ефективними для корекції ефектів дисперсії ультракотких імпульсних сигналів.