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Multicomponent Chirp-like Jammer Excision in DSSS Communication Systems Using Hilbert-Huang Hough Transform

Yuan Ye*[1], Mei Wenbo[2]
[1]School of Information Engineering, Beijing Institute of Fashion Technology Beijing 100029, China
[2]School of Electronic and Information Engineering, Beijing Institute of Technology Beijing 100081, China
*Corresponding author, e-mail: colayuan@163.com

Abstract

A novel and efficient approach for multicomponent chirp-like jammer excision in direct sequence spread spectrum (DSSS) communication systems using Hilbert-Huang Hough (HH-H) transform is proposed, which is the generalization of marginal Hilbert spectrum. The approach iteratively decomposes the received signal into intrinsic mode functions (IMFs) and applies Hilbert transform to each IMF to yield Hilbert spectrum (HS), by which the embedded jammers can be well concentrated in the time-frequency plane along their instantaneous frequency laws. By performing Hough transform over the HS and searching peaks in the parameter space, parameters estimation and components reconstruction of the multicomponent chirp-like jammer are implememted. Simulation results are presented showing performance comparison between the proposed method and the fractional Fourier transform (FrFT) based method in the case of two chirp-like jammer components.

Keywords: *chirp-like jammer excision, DSSS communication system, empirical mode decomposition, hilbert spectrum, hilbert-huang hough transform*

1. Introduction

A DSSS communication system is characterized by spreading the information signal spectrum over a broad frequency band by modulating it with a spreading code signal before transmission [1].Thus the transmitted signal of a DSSS communication system occupies a much wider bandwidth than the bandwidth necessary to send the information. As nonstationary signals with large time-bandwidth product, chirp-like signals generally serve as intentional jammers in DSSS communication systems. Therefore many contributions have dealt with the excision of such chirp-like jamming signals which possess time-varying frequency characteristics. Most of these methods focus on excising the jammers using time frequency distributions (TFDs) [2-5]. The localized jammers can be obtained in the time-frequency plane by performing short-time Fourier transform on the received signal [6]. However the selection of the data window cannot be adaptive [7, 8], which limits its application in practice. Wigner-Hough transform [9] uses the line-integration through the Wigner-Ville distribution (WVD) to localize the chirp-like jamming signals in parameter space and to estimate instantaneous frequency (IF) of each jammer component. After the Ifs are estimated, jammer components are thus excised by the adaptive filter placed at their IFs. Although Wigner-Hough transform is an effective tool for analyzing multicomponent chirp-like signals, it is time-consuming and also suffers from the interference of cross terms. Based on the properties that the localization performance of a Chirp signal varies in different fractional Fourier domains and that the fractional Fourier transform (FrFT) is free of the interference of cross terms, the detection and parameter estimation of the jamming signal are implemented in fractional Fourier domain and the reconstructed jamming signals are then excised from the received signal [10]. But in the case of a finite Chirp signal, sidelobe effect causes difficulties in interpreting the spectrum in fractional domain.

Hilbert-Huang transform [11] is a newly proposed method for signal processing, which uses intrinsic time scales to decompose the signal instead of the predefined basis functions. It is very suitable for the analysis of nonlinear and nonstationary signals. When generalizing Hilbert-Huang transform to Hilbert-Huang transform to Hilbert-Huang Hough transform, a novel method

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for the excision of multicomponent chirp jammer is proposed in which the detection and parameters estimation of the chirp jammer components are implemented using Hilbert-Huang Hough transform and the reconstructed jammer components are then excised from the received signal in time domain. The superiorities of the technique over fractional Fourier transform is verified by simulation experiments, especially under the condition of high jammer to signal ratios.

2. Hilbert-Huang Hough Transform

The Hilbert-Huang transform is composed of empirical mode decomposition (EMD) and Hilbert transform. The EMD decomposes the analyzed signal into some oscillatory components called intrinsic mode function. The Hilbert spectrum is constructed by applying Hilbert transform to every real valued IMF component.

2.1. Empirical Mode Decomposition

The principle of EMD is to decompose any signal into a set of intrinsic oscillatory modes in terms of characteristic time scales. By definition an IMF should satisfy two conditions: (1) the number of extrema and zero-crossings of the signal must be the same or differ by no more than one, (2) the mean of the envelope defined by the local maxima and the envelope defined by the local minima is always zero. For a one-dimensional signal $s(n)$, $n = 0,1,\cdots,N-1$, the EMD algorithm can be summarized as follows.

1) Initialize the residue $r_0(n) = s(n)$ and the IMF index $j = 1$

2) Extract j th IMF component
   (i) Set $h_0(n) = r_{j-1}(n)$, $k = 1$
   (ii) Identify all the local maxima and local minima from $h_{k-1}(n)$
   (iii) Interpolate all the local maxima and local minima respectively by cubic splines to obtain upper and lower envelopes
   (iv) Compute mean envelope $m_{k-1}(n)$ of the upper and lower envelopes
   (v) Update $h_k(n) = h_{k-1}(n) - m_{k-1}(n)$ and $k = k+1$
   (v1) Repeat steps (ii)-(v) until $h_k(n)$ being an IMF. If so, the j th IMF $c_j(n) = h_k(n)$ and update residue $r_j(n) = r_{j-1}(n) - c_j(n)$

3) Repeat step 2) with all the subsequent $r_j(n)$'s

Finally the given signal $s(n)$ is represented by:

$$s(n) = \sum_{j=1}^{M} c_j(n) + r_M(n) \tag{1}$$

Where M is the number of IMF components and $r_M(n)$ is the final residue.

2.2. Hilbert Spectrum

For each IMF component $c_j(n)$, its discrete time Hilbert transform is defined as [12]:

$$\mathrm{H}\left[c_j(n)\right] = \frac{1}{\pi} \sum_{\delta=-\infty}^{\infty} \frac{c_j(n)}{n-\delta}, \quad n \neq \delta \tag{2}$$

Then the analytic expression of the i th is defined as

$$Z_j(n) = c_j(n) + j\mathrm{H}\left[c_j(n)\right] = a_j(n) e^{j\phi_j(n)} \tag{3}$$

Where $a_j(n)=\sqrt{c_j^2(n)+\mathrm{H}^2\left[c_j(n)\right]}$ and $\phi_j(n)=\arctan\frac{\mathrm{H}\left[c_j(n)\right]}{c_j(n)}$ are instantaneous amplitude and phase respectively. After unwrapping instantaneous phase $\phi_j(n)$, the discrete time IF of the j th IMF is then computed as the difference of the phase $\phi_j(n)$ at time instant n :

$$\omega_j(n)=\mathrm{diff}\left[\phi_j(n)\right] \tag{4}$$

Where $\mathrm{diff}[\cdot]$ represents the difference operation. The total Hilbert spectrum is expressed as the superposition of all IMFs' HSs, i.e.

$$H(\omega,n)=\sum_{j=1}^{M}a_j(n)\eta_j(n), \tag{5}$$

Where:

$$\eta_j(n)=\begin{cases}1, & \text{if } \omega_j(n) \text{ takes the value } \omega \\ 0, & \text{otherwise}\end{cases}. \tag{6}$$

2.3. Hilbert-Huang Hough Transform

The line integration along IFs of the Hilbert spectrum can further localize chirp like signals in the parameter space [13, 14]. Hilbert-Huang Hough transform firstly proposed in authors previous work is the generalization of marginal Hilbert spectrum by applying line integration along IFs to the Hilbert spectrum [13]. For a discrete time signal $s(n)$, the Hilbert-Huang Hough transform is given by the following expression:

$$h(\mathbf{\Theta})=\sum_{n=0}^{N-1}H(\omega,n)=\sum_{n=0}^{N-1}H\left(\omega(n;\mathbf{\Theta}),n\right), \tag{7}$$

Where $H(\omega,n)$ is the Hilbert spectrum, and $\omega(n;\mathbf{\Theta})$ is the parameterized IF satisfying $\omega(n;\mathbf{\Theta})=diff\left[\phi(n;\mathbf{\Theta})\right]$. For a chirp signal, the instantaneous phase $\phi(n;\mathbf{\Theta})$ can be denoted by

$$\phi(n;\mathbf{\Theta})=\omega_0 n+mn^2,\ \mathbf{\Theta}=(\omega_0,m). \tag{8}$$

In the above expression, ω_0 is the initial angular frequency and m is the chirp rate.

3. DSSS System Model

A typical DSSS system is shown in Figure 1. In this system, the transmitter generates a spread spectrum (SS) sequence modulated BPSK signal, which is transmitted over a communication channel. Channel noise as well as jammers are superimposed on the transmitted BPSK signal. At the receiver, the noise and jammer corrupted signal is first demodulated. With the jammers excised from the demodulated signal, the SS receiver correlates the baseband SS signal with the synchronized PN sequence, and the resulting signal is then input into a threshold detector to estimate the binary data sequence.

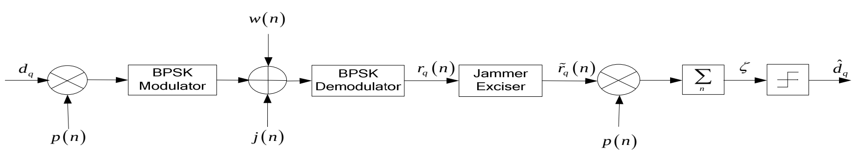


Figure 1. Block Diagram of a DSSS System

Let $d_q \in \{-1,+1\}$ be the qth message symbol transmitted in the DSSS system, and $p(n)$ be a PN sequence with a chip length N. The spread spectrum is achieved by multiply d_q by $p(n)$. After BPSK demodulation, the received signal $r_q(n)$ consists of the SS signal with power ε, the additive white Gaussian noise $\mathrm{W}(n)$, and the multicomponent jammer $\mathrm{J}(n)$ such that:

$$r_q(n) = \sqrt{\varepsilon} d_q p(n) + \mathrm{J}(n) + \mathrm{W}(n), \quad 0 \le n \le N-1. \tag{9}$$

The multicomponent jammer can be modeled as:

$$\mathrm{J}(n) = \sum_{\ell=11}^{L} a_{0\ell} \exp\left(i\varphi_{0\ell} + i\omega_{0\ell} n + i m_\ell n^2\right), \tag{10}$$

Where $a_{0\ell}, \varphi_{0\ell}, \omega_{0\ell}, m_\ell$ are unknown parameters of the ℓth chirp-like jammer component, and L is the number of jammers. The jammer excised signal $\tilde{r}_q(n)$ is correlated with $p(n)$ to determine the test statistic:

$$\zeta = \sum_{n=0}^{N-1} \tilde{r}_q(n) p(n), \tag{11}$$

Which is used to estimate the transmitted message element as:

$$\hat{d}_q = \begin{cases} 1 & \zeta \ge 0 \\ -1 & \zeta < 0 \end{cases}. \tag{12}$$

4. Excision Algorithm

Figure 2 provides an overview of the proposed algorithm. It's assumed that the jamming signals are chirp-like signals, and the number of jamming signals is available.

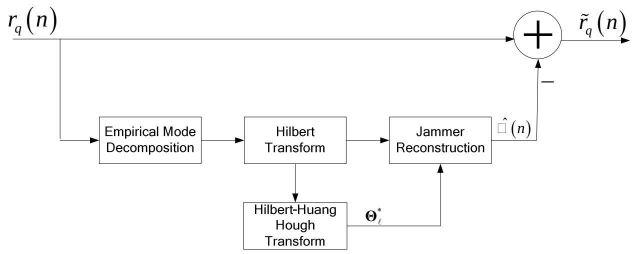


Figure 2. Jammer Exciser

Step 1. Decompose the received baseband signal $r_q(n)$ into IMFs using EMD. Model as sum of IMF components.

Step 2. Apply discrete-time transform to each IMF component $c_j(n)$ to construct Hilbert spectrum.

$$H(\omega,n) = \sum_{j=1}^{M} H_j(\omega,n) \tag{13}$$

where $H(\omega,n)$ is the total Hilbert spectrum, and $H_j(\omega,n)$ is the Hilbert spectrum of $c_j(n)$.

Step 3. Compute the Hilbert-Huang Hough transform using expression (7) to obtain $h(\boldsymbol{\Theta})$, $\boldsymbol{\Theta} = (\omega_0, m)$.

Step 4. Determine the quantized parameter vector $\boldsymbol{\Theta}_\ell^* = (\omega_{0\ell}, m_\ell)$ corresponding to ℓth maximum of $h(\boldsymbol{\Theta})$. Construct the ℓth jammer component as follows.

$$\hat{J}_\ell(n) = H(\omega_{0\ell} + m_\ell n, n)\cos\left[\phi(\omega_{0\ell} + m_\ell n, n)\right] \tag{14}$$

Step 5. Perform the masking operation on the ℓth peak of $h(\boldsymbol{\Theta})$.

$$\tilde{h}(\boldsymbol{\Theta}) = h(\boldsymbol{\Theta})M(\boldsymbol{\Theta}) \tag{15}$$

Where:

$$M(\boldsymbol{\Theta}) = \begin{cases} 0, & \text{if } \boldsymbol{\Theta} \in \mathbf{R}(\omega_{0\ell}, m_\ell) \\ 1, & \text{otherwise} \end{cases} \tag{16}$$

and $\mathbf{R}(\omega_{0\ell}, m_\ell)$ is the narrowband region of the (ω_0, m) plane centred at point $(\omega_{0\ell}, m_\ell)$.

Step 6. Repeat step 4 and step 5 until all jammer components are estimated. Then reconstruct the multicomponent jammer as:

$$\hat{J}(n) = \sum_{\ell=1}^{L} \hat{J}_\ell(n) \tag{17}$$

Step 7. Determine the jammer excised SS signal $\tilde{r}_q(n)$ by subtracting the reconstructed multicomponent jammer from the received signal $r_q(n)$.

$$\tilde{r}_q(n) = r_q(n) - \sum_{\ell=1}^{L} \hat{J}_\ell(n) \tag{18}$$

5. Simulation Results and Discussion

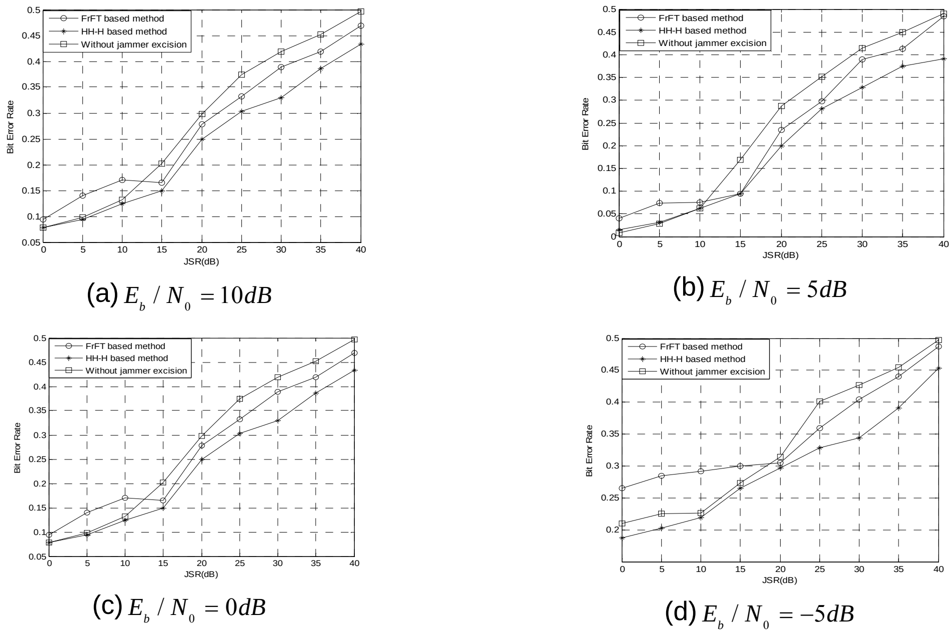
In the simulation, the received SS signal contains 128 message symbols with 32 chips per message symbol.

To measure the performance of the DSSS communication system with the proposed jammer excision approach, bit error rates (BERs) are evaluated in the presence of a multicomponent

Jammer of two linear chirps with normalized initial frequencies are $\omega_{01} = 0.1\pi$, $\omega_{02} = 0.4\pi$, and the normalized chirp rates are $m_1 = 0.244 \times 10^{-4}\pi$, $m_2 = 0.732 \times 10^{-4}\pi$, and the initial phases are $\varphi_{01} = \varphi_{02} = 0$.

The value of jammer to signal power ratio (JSR) varies from 0dB to 40dB with an interval of 5dB. At each level of JSR, 1000 Monte Carlo simulations are run. Figure 3 (a)-(d) have shown the simulation results for calculating BERs when the signal to noise power ratio E_b / N_0 values are 10dB, 5dB, 0dB and -5dB respectively. As a comparison, the BERs of the DSSS receiver with FrFT based jammer excision approach and without jammer excision have also been presented.

It is shown from the simulation results that the introduction of jammer excision in a DSSS communication system substantially improve the BER performance when the JSR values are relatively high. The Hilbert-Huang Hough transform based method outperforms the FrFT based method. There exists a distinct BER difference between these two methods. The average difference BER values of the four cases mentioned above are approximately 2%, 2.96%, 5.52%, 4.56% and 6.47% when JSR is larger than 15dB.



(a) $E_b / N_0 = 10dB$ (b) $E_b / N_0 = 5dB$

(c) $E_b / N_0 = 0dB$ (d) $E_b / N_0 = -5dB$

Figure 3. Bit error rate versus JSR for E_b / N_0 =10dB, 5dB, 0dB and -5dB

6. Conclusion

A novel method based on Hilbert-Huang Hough transform for multicomponent chirp-like jammer excision of DSSS system is proposed. The detection and parameter estimation of the jammer components are implemented by using Hilbert-Huang Hough transform to map the received SS signal into parameter space. The jammer components are then reconstructed in time domain and subtracted from the received SS signal. The proposed method can not only avoid the interference of cross terms in quadratic TFDs but also eliminate the interference of sidelobes in FrFT due to the finite length effect. The jammer excision method based on Hilbert-Huang Hough transform is thus superior to that based on fractional Fourier transform.

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