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Wigner-Hough transform based on slice's entropy and its application to multi-LFM signal detection

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Abstract: To enhance the capacity of the radar-reconnaissance interception receiver recognizing linear frequency modulated (LFM) at a low signal-noise ratio, this paper presents Wigner-Hough transform (WHT) of the LFM signal and its corresponding characteristics, derives the probability density functions of the LFM signal and Gaussian white noise within WHT based on entropy (WHTE), dimension under different assumptions and puts forward a WHT algorithm based on entropy of slice to improve the capacity of detecting the LFM signal. Entropy of the WHT domain slice is adopted to assess the information size of polar radius or angle slice, which is converted into the weight factor to weight every slice. Double-deck weight is used to weaken the influences of noise and disturbance terms and WHTE treatment and signal detection procedure are also summarized. The rationality of the algorithm is demonstrated through theoretical analysis and formula derivation, the efficiency of the algorithm is verified by simulation comparison between WHT, fractional Fourier transform and periodic WHT, and it is highlighted that the WHTE algorithm has better detection accuracy and range of application against strong noise background.

Keywords: low signal-to-noise ratio, linear frequency modulated signal, probability density function, Wigner-Hough transform (WHT), signal detection, entropy of slice.

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1. Introduction

Since the linear frequency modulated (LFM) signal has the large time bandwidth product, it is used widely in radar, sonar and earthquake detection systems. In modern radar, the LFM signal has the functions of improving radar interception and target tracking; meanwhile, it also has strong resolving power of distance and dimension in enhancing target differentiation [1,2]. The LFM signal plays a significant role in detection and it has become the important target of electronic countermeasure detection and differentiation [3].

At present, many scholars have studied extensively detection of LFM signals with abundant achievements. References [4,5] adopted fractional Fourier transformation (FrFT) to differentiate LFM signals and obtained good energy focusing time-frequency representation, which could help in signal detection; however, when the frequency spectrum of LFM signals overlapped at a low signal to noise ratio (SNR), the efficiency of signal detection would be limited and two-dimensional search would be needed when FrFT was treated, which would cause a large increase of computation. Reference [6], based on the compressed sensing theory, realized efficient detection of LFM signals at the low SNR and with smaller sampling number, whose anti-noise performance was restricted by prior knowledge. References [7,8] extracted wavelet ridge of LFM signals after conversion and conducted cluster matching weighting on straight lines with vague C-means to enhance detection precision and widen the range of application; however, there existed interference of subjective factors in selecting empirical parameters, especially efficiency limitation when there was no prior knowledge. References [9,10] adopted the cycle Wigner-Hough transform (WHT) method to realize good detection of LFM signals with signal designing and WHT; however, since algorithm performance was related with prior knowledge, it would consume plenty of system resources when designing matching items of passive detection and the instantaneity would be affected.

To deal with disadvantages mentioned above and combining information entropy theory and WHT conversion, this paper puts forward the recognition method of multiple LFM signals with WHT based on entropy (WHTE). Theoretically, since noises do not contain useful information, the noise information in slices of each converted WHT would be larger than the LFM signal; therefore, its weight would be small and correspondingly the signal after

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WHT conversion and weighted treatment would be weakened; however, since the WHT itself has the capacity of restricting interfering factors, the influences of noises and the cross-product terms would be weakened also. Treatment of information entropy could endow different weights on different WHT slices, which could weaken the influences of noises and interfering factors and is helpful in increasing the detection performance of LFM signals.

The algorithm proposed in this paper is a kind of filter designing methods based on data-driven computation. It is to endow different weights based on the influences of the final detection to avoid intervention of subjective factors and to increase the instantaneity of the system directly with numerical computation. This paper demonstrates the feasibility of the method through theoretical derivation and verifies the practicability of the computation by comparing the classical and the improved computations.

2. WHTE

2.1 LFM signal model and WHT

Wigner-Ville distribution (WVD) of the signal $s(t) \in \boldsymbol{L}^2(\boldsymbol{R})$ could be defined [11,12] as

$$\mathrm{WVD}_z(t,f)=\int_{-\infty}^{\infty} z\left(t+\frac{\tau}{2}\right)z^*\left(t-\frac{\tau}{2}\right)\mathrm{e}^{-2\mathrm{j}\pi\tau f}\mathrm{d}\tau. \tag{1}$$

In the above formula, $z(t)$ is the analytic signal. Through WVD conversion, the signal of time dimension is converted into $\mathrm{WVD}_z(t,f)$ in two time-frequency dimensional domains, based on which the features of the signal in two time-frequency dimensions could be extracted. The typical pattern of the LFM signal adopted by the radar system is as follows:

$$z(t)=\mathrm{e}^{-\mathrm{j}2\pi\left(f_0 t+\frac{1}{2}mt^2\right)}. \tag{2}$$

The WVD of the LFM signal thus obtained is

$$\mathrm{WVD}_{(\mathrm{LFM})}(t,f)=$$

$$\int_{-\infty}^{\infty} z\left(t+\frac{\tau}{2}\right)z^*\left(t-\frac{\tau}{2}\right)\mathrm{e}^{-2\mathrm{j}\pi\tau f}\mathrm{d}\tau=$$

$$\int_{-\infty}^{\infty}\mathrm{e}^{\mathrm{j}2\pi(f_0+mt)\tau}\mathrm{e}^{-\mathrm{j}2\pi\tau f}\mathrm{d}\tau=\delta[f-(f_0+mt)] \tag{3}$$

$$z\left(t+\frac{\tau}{2}\right)z^*\left(t-\frac{\tau}{2}\right)=\mathrm{e}^{\mathrm{j}2\pi\left[f_0\left(t+\frac{\tau}{2}\right)+\frac{1}{2}m\left(t+\frac{\tau}{2}\right)^2\right]}\times$$

$$\mathrm{e}^{\mathrm{j}2\pi\left[f_0\left(t-\frac{\tau}{2}\right)+\frac{1}{2}m\left(t-\frac{\tau}{2}\right)^2\right]}=\mathrm{e}^{\mathrm{j}2\pi(f_0+mt)\tau}. \tag{4}$$

The integral result of the above formula is

$$\int_{-\infty}^{\infty}\mathrm{e}^{-\mathrm{j}2\pi[f-(f_0+mt)\tau]}\mathrm{d}\tau=\delta[f-(f_0+mt)]. \tag{5}$$

It could be known from the definition of impulse function that WVD two-dimensional distribution figure of the ideal infinite long LFM signal is an $f=f_0+mt$ straight line. Then, the straight line detection could be conducted with Hough conversion.

Hough conversion is actually the straight integral along the t-ω plane. At standard parameterization, the expression of Hough conversion is

$$\rho=t\cos\theta+\omega\sin\theta,\quad \rho\geqslant 0,\quad 0\leqslant\theta\leqslant\pi$$

$$\omega=2\pi f. \tag{6}$$

From the above formula, it could be known that if there is a straight line on the time-frequency plane, the peak value would appear in the ρ-θ domain. On the time-frequency plane, if intercepts ω_0 and k of ω are used to describe the straight line, when integrating along $\omega=\omega_0+kt$, the integral transformation could then be conducted on the integrand.

$$\begin{cases}\omega_0=\dfrac{\rho}{\sin\theta}\\ k=-\cot\theta\end{cases} \tag{7}$$

Combining WVD and Hough transform (HT), the linear WHT of the signal could then be obtained:

$$\mathrm{WHT}_s(\rho,\theta)=$$

$$\int_{-\infty}^{\infty}\int_{-\infty}^{\infty}\mathrm{WVD}_{(\mathrm{LFM})}(t,\omega)\delta(\omega-\omega_0-kt)\mathrm{d}\omega\mathrm{d}t=$$

$$\int_{-\infty}^{\infty}\mathrm{WVD}_{(\mathrm{LFM})}(t,\omega_0)\mathrm{d}t,\quad \omega_0\neq kt. \tag{8}$$

It could be seen from the above formula since time-frequency conversion of the LFM signal is a straight line with the focused energy on the t-ω plain, after Hough conversion, it is a peak value in the ρ-θ domain; when the parameter of the signal deviates from ω_0 and k, the corresponding integral value would decrease quickly. However, the WHT conversion of the noise has no rule and though the cross term of the signal could affect the differentiation of the LFM signal, the parameter after the WHT conversion of the cross term is not near ω_0 and k. So, theoretically, the detection of the LFM signal with the WHT conversion could restrict well the disturbance of the cross term and the noise.

Though the WHT could obtain better treatment results, its range of application is limited. With the decreasing SNR, the result obtained from WHT conversion would be submerged in noises and the false peak value would be easily obtained when searching the most value. Though the WHT changes could weaken the influences of cross items after the WVD conversion, the obtained WHT conversion result still remains cross item, which could in turn affect detection of LFM signals.

Therefore, this paper adopts the ideology of information entropy determining weights to slice the WHT signal in the ρ-θ domain based on the polar radius and angle and to conduct similar weighted approach on different points to enhance the applicability of WHT.

2.2 Basic procedure of information entropy determining weights

Information entropy was first put forward by Shannon in 1948 to describe the disorder parameter of information [13]. Disorder parameter of information has negative correlation with information effectiveness, so information entropy could be used to measure the effective information contained in the evaluation object. Based on this, scholars raised the entropy weight method to calculate the corresponding weights endowed by different features of the research object so as to achieve the objectives of highlighting the feature and weakening generality, which could make the features of the research objects easy for extraction and separation.

Suppose there are n objects and m evaluation indexes and the matrix of the original data is $\boldsymbol{X} = [x_{ij}]_{n*m}$, $x_{ij} \geqslant 0$ $(i = 1, 2, \ldots, n; j = 1, 2, \ldots, m)$. $x_{ij} \geqslant 0$ is the value range of guaranteeing p_{ij} within [0,1] after the mean value conversion. If $x_{ij} < 0$, it could be treated positively with the similar method. Since the value range of the variable in entropy is [0,1], to meet the requirement, it is necessary to pre-treat the raw data, i.e. to adopt normalization method [14,15]:

$$p_{ij} = \frac{x_{ij}}{\sum\limits_{j=1}^{m} x_{ij}}. \tag{9}$$

The matrix obtained from the treatment is $\boldsymbol{P} = [p_{ij}]_{n*m}$. The information entropy E_j of each attribute is calculated as follows:

$$E_j = -k \sum_{i=1}^{n} (p_{ij} \ln p_{ij}). \tag{10}$$

In the above formula $k = 1/\ln n$, meanwhile, if $p_{ij} = 0$, it is stipulated $p_{ij} \ln p_{ij} = 0$. The entropy weight ω_j of the jth index is defined as

$$\omega_j = \frac{1 - E_j}{\sum\limits_{j=1}^{m} (1 - E_k)}. \tag{11}$$

It could be seen from the above formula that the information entropy is in negative correlation with the changing degree of the index value, that is to say, the larger the information entropy is, the less information it could provide; and therefore, the function of the final research result would be weaker and the corresponding entropy weight would be smaller [16]. The entropy weight method uses the information contained in the index to calculate the weight. Thus, the entropy weight method is not only objective but could also get weight with the higher accuracy in the evaluation of the index variation.

2.3 Improving WHT based on information entropy

Since the detection result of the LFM signal at a low SNR with the existing WHT conversion is not satisfactory, in which there still remains the cross item at the ρ-θ plane restricting the detection performance of the LFM signal, this paper puts forward the WHTE algorithm by combining the information entropy theory and the WHT algorithm to expand the application scope of the WHT algorithm. The specific procedure is shown in Fig. 1.

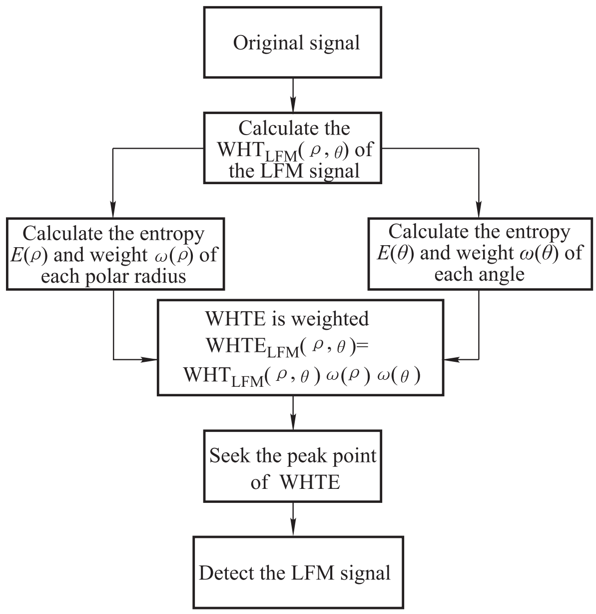


Fig. 1 Procedure of LFM signal treatment with WHTE method

First of all, (8) is used in the WHT conversion of the LFM signal to compute the information entropies $E(\rho)$ and $E(\theta)$ of each polar radius ρ and angle θ slice after WHT conversion combining formulas (9) and (10). Since the noise disorder is far larger than the LFM signal, the larger the information entropy is, the less information it contains. Then, the weights $\omega(\rho)$ and $\omega(\theta)$ of various polar radii and angles are calculated with (11), which is multiplied with $\mathrm{WHT_{LFM}}$ and then $\mathrm{WHTE_{LFM}}$ is obtained. Conduct the peak value search of the final result to realize the detection of the LFM signal.

The core of the WHTE algorithm is to compute the information entropies of each polar radius ρ and angle θ slice after the WHT, quantize the information size contained in the tangent plane and to measure the influences of different slices on detection efficiency with weights. Slice with large information would be distributed with large weight while slice with small slice would be given small weight. And then multiply the results of WHT treatment with the weight results respectively with the ρ-θ two-dimension combined treatment so as to retain the information of the peak point to be detected and to weaken irrelative disturbance variables. In this way, the detection performance of the LFM signal could be enhanced.

3. Detecting algorithm of the LFM signal

In terms of electron reconnaissance, the intercepted prior information of the opponent's radar emitter signal is limited, which is hard to support signal matching and detection. Therefore, this paper treats detection of various LFM signals with the statistical method, converting differentiation of multiple LFM signals into multiple binary hypothesis testing within the ρ-θ dimension, that is, to divide signals into signal noise mixing zone and noise zone by setting threshold. Suppose that $s(t)$ is the LFM signal, $n(t)$ is the noise, then the above mentioned binary hypothesis testing could be expressed:

$$\begin{cases} H_0 : x(t) = n(t), \quad \text{noise} \\ H_1 : x(t) = s(t) + n(t), \quad \text{signal and noise} \end{cases}. \tag{12}$$

To enhance the signal treatment efficiency of the detecting system, the Neyman-Pearson rule is adopted to design the detector so as to guarantee more useful information which could enter the system and to avoid too much false data entering the detector to affect the working efficiency of the system, i.e., when the false alarm probability P_F is constant, its detection probability P_D is the largest. Since the WHT form of the LFM signal is strong peak value within the ρ-θ dimension, it is supposed that the detection threshold α is used to detect the signal and the noise and the detection statistics $l(\rho,\omega)$ is set as

$$l(\rho,\omega) = |\mathrm{WHT}_{\max}(\rho,\omega)|. \tag{13}$$

Thus, the detection probability P_D and the false alarm probability P_F of the signal could be expressed as

$$P_F = \int_{\alpha}^{\infty} p(l|H_0)\mathrm{d}l \tag{14}$$

$$P_D = \int_{\alpha}^{\infty} p(l|H_1)\mathrm{d}l. \tag{15}$$

The Neyman-Pearson rule is constant false alarm detection, i.e, to suppose that P_F is definite value P_{Fc}. Conduct the improper integral at variable low limit on the probability density function $p(l|H_0)$ of the test statistics $l(\rho,\omega)$ at H_0 condition with (14) and make the integral value be P_{Fc}. Then the integral low limit could be obtained, i.e. the threshold α to be determined. Integrate with (15) and the optimal detection probability P_D could be obtained.

Thus, before constant false alarm detection, acceptable false alarm rate P_{Fc} of the system should be set first and the detection threshold of the system should be determined based on the false alarm rate P_{Fc} and the statistical feature of noises. That is, the basis of the peak value detection is to determine the statistical feature of the signal within the ρ-θ dimension.

The radar reconnaissance interception receiver could conduct the passive detection in wide and open areas. Generally, the signal received by the reconnaissance receiver does not contain other noises. It is mainly the hot noise within the system and the statistical property is generally Gaussian white noise. The noise $n(t)$ received by the system complies with the standard normal distribution with the mean value of 0 and the variance of 1. Conduct the WHT on noise with (8) and the following formula could be obtained:

$$\mathrm{WHT}_n(\omega_0,k) = \int_{-\infty}^{\infty}\int_{-\infty}^{\infty} n\left(t+\frac{\tau}{2}\right) n\left(t-\frac{\tau}{2}\right)\cdot \mathrm{e}^{-\mathrm{j}2\pi(\omega_0+kt)\tau}\mathrm{d}\tau\mathrm{d}t. \tag{16}$$

Disperse the above formula and the following result could be obtained:

$$\mathrm{WHT}_n(\omega_0,k) = \sum_{m=0}^{N/2-1}\sum_{a=-m}^{m} n(m+a)n^*(m-a)\mathrm{e}^{-\mathrm{j}4\pi(\omega_0+km)a} + \sum_{m=N/2}^{N-1}\sum_{k=-(N-1-M)}^{N-1-m} n(m+a)n^*(m-a)\mathrm{e}^{-\mathrm{j}4\pi(\omega_0+km)a}. \tag{17}$$

For the discrete signal $n(m)$, $m = 0, 1, \ldots, N-1$.

Instantaneous correlation function whose expression is signal could be obtained from (17). Since the Gaussian white noise is not 0 only when the time delay is 0, i.e., $a = 0$, the correlation function of the signal is not 0. Substitute $a = 0$ in (17) and it could be obtained:

$$\mathrm{WHT}_n(\omega_0,k) = \sum_{m=1}^{N}[n(m)]^2 \sim \chi^2(N). \tag{18}$$

The above formula shows that the WHT statistical feature of the Gaussian white noise complies with χ^2 distribution whose variance is N.

Since either signal or noise should be treated with a double weighted approach with information entropy, though the mean value of the noise signal would not change, its statistical average is not necessarily 0 due to the limited signal length. Thus, the statistical average must be subtracted before detection. Meanwhile, the treatment of the information entropy could cause the change of noise variance, which is no longer 1, so, the noise must be standardized.

Suppose the noise variance after the information entropy treatment is σ^2. Since the weight is obtained through calculation and it is known $\sigma^2 \neq 1$, the following could be obtained:

$$\frac{n(m)-\bar{n}}{\sigma} \sim N(0,1) \tag{19}$$

where $N(0,1)$ shows the standard normal distribution. From (18) and (19), it could be obtained:

$$\frac{\mathrm{WHT}_n(\omega_0,k)}{\sigma^2} = \sum_{m=1}^{N}\left[\frac{n(m)-\bar{n}}{\sigma}\right]^2 \sim \chi^2(N). \tag{20}$$

It could be known from [10], at H_0, when the Gaussian white noise complies with the χ^2 distribution of the variance N, the probability distribution function of the test statistic l is

$$p(l|H_0) = \begin{cases} \dfrac{1}{2^{N/2}\Gamma(N/2)} l^{N/2-1}\mathrm{e}^{-l/2}, & l > 0 \\ 0, & \text{others} \end{cases}. \tag{21}$$

Once the probability density function of the test statistics l at H_0, integration could then be conducted with (14). Combining the pre-set false alarm probability P_{Fc}, the detection threshold α could then be obtained. Meanwhile, at H_1, the test statistic l complies with χ^2 distribution whose variance is N. The starting point of the curve of its probability density function move right $N^2/2$ along x-coordinate. Then the detect probability P_D of the signal could be determined with (15).

The above mentioned treatment procedure is shown in Fig. 2.

Fig. 2 is the detection part of Fig. 1. Through the above procedure, LFM signal detection could be conducted after the information entropy weighted handling of the signal.

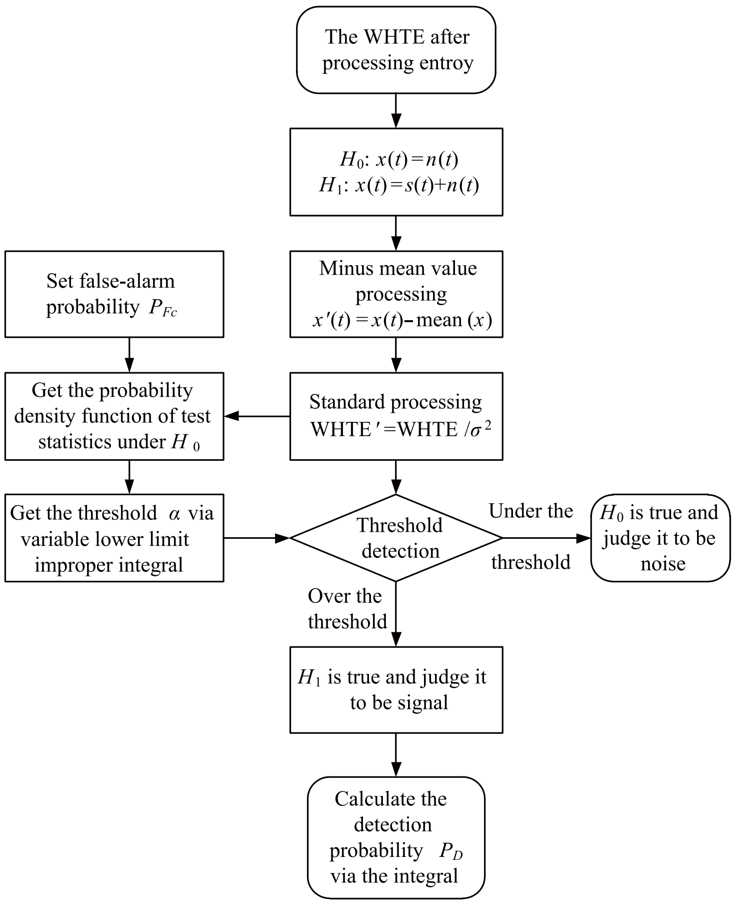


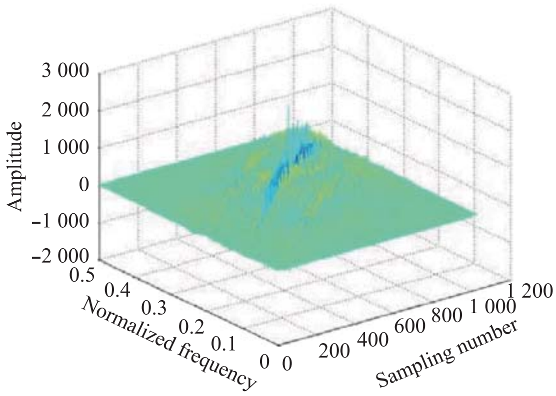
Fig. 2 LFM signal detection procedure of WHT based on slice entropy weight

4. Simulations

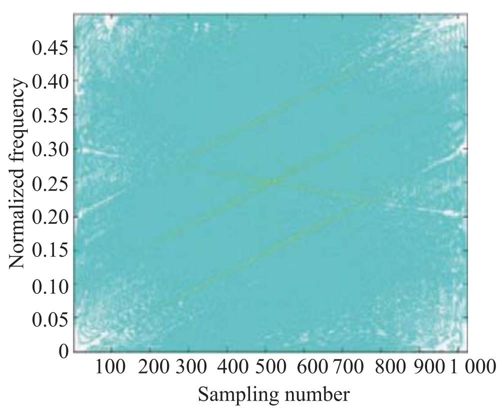
The algorithm is first adopted to detect each signal while analyzing its computation complexity. Then, the simulation is conducted to verify the detecting capacity of the algorithm proposed in this paper for multiple aliasing LFM signals at different SNRs. Then, the improved and classical algorithms are compared to highlight the efficiency of the improved algorithm.

The simulation condition is to set mixing signal of three groups of LFM signals and Gaussian white noise. The variation ranges of the three groups LFM signals are orderly [0, 30] MHz, [20, 50] MHz and [30, 20] MHz; the sampling frequency $f_s = 100$ MHz, the total sampling points $N = 1\ 024$, the total observation time is still $T_t = N/f_s = 10.24$ μs, the frequency fluctuation ratio $\Delta f_1 = 2.93$ MHz/μs, $\Delta f_2 = 2.93$ MHz/μs, $\Delta f_3 = 0.97$ MHz/μs; the initial phase φ is selected randomly within $[0, 2\pi]$. The false alarm probability is set as 0.01 and the SNR is set respectively as -3 dB and -15 dB. The simulation results of the simulation verification with the algorithm adopted in this paper is shown as the follows.

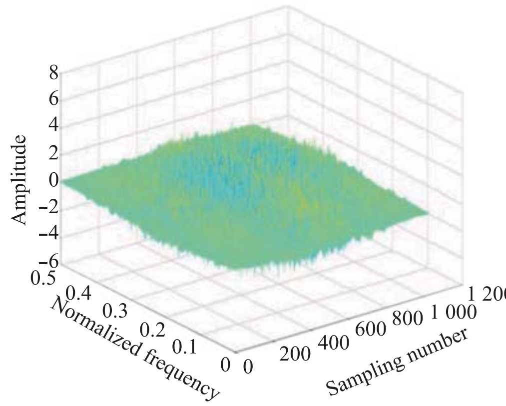
It could be seen from Fig. 3(a) and Fig. 3(b) that WVD distributions of three LFM signals are three straight lines.



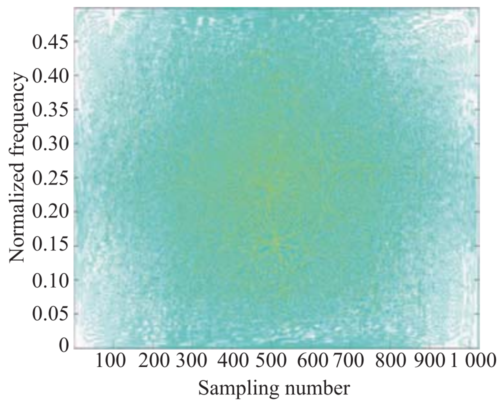
(a) WVD three-dimension figure of −3 dB multiple LFM signals



(b) WVD time-frequency figure of −3 dB multiple LFM signals



(c) WHT three-dimension figure of −15 dB multiple LFM signals

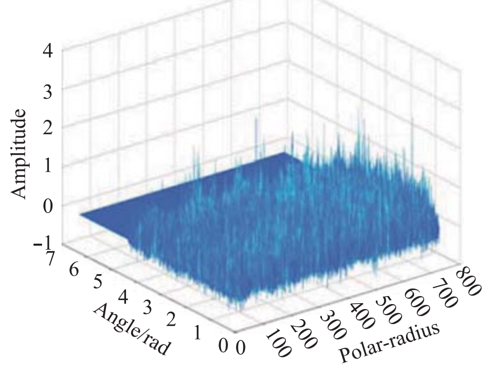


(d) WVD time-frequency figure of −15 dB multiple LFM signals

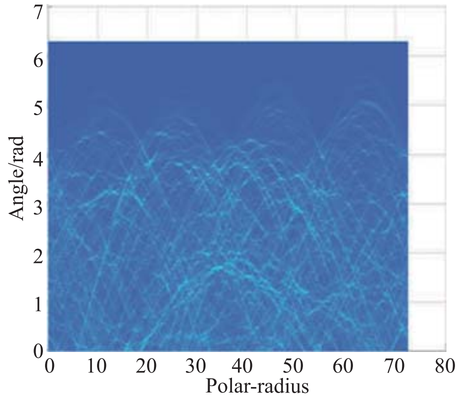
Fig. 3 WVD figures of multiple LFM signals

Since the WVD distribution does not have linear additivity, cross aliasing item appears, i.e. the fourth straight line in Fig. 3. The cross item restricts severely WVD detection, restricting its range of application. Meanwhile, it could also be seen obviously from Fig. 3(c) and Fig. 3(d) that with the lowering of SNR, the LFM signal would be submerged under strong noises, which makes it impossible to identify LFM.

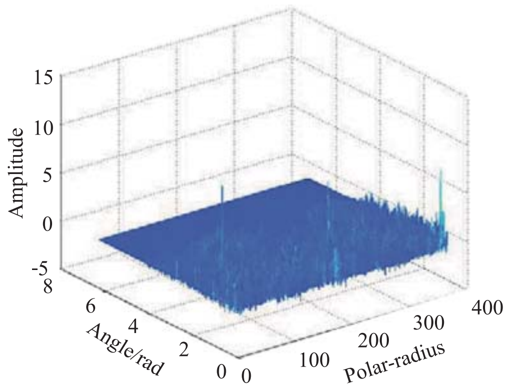
Conduct WHT and WHTE treatments on the multiple LFM signal at -15 dB and it could be obtained in Fig. 4.



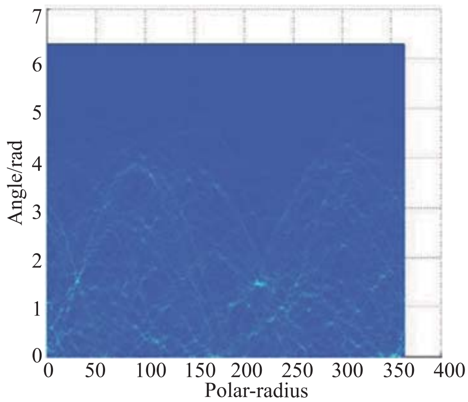
(a) WHT three-dimension figure of multiple LFM signals



(b) WHT ρ-θ figure of multiple LFM signals



(c) WHT three-dimension figure of multiple LFM signals



(d) WHT ρ-θ figure of multiple LFM signals

Fig. 4 WHT and WHTE figures of information entropy at −15 dB before and after treatments

It could be seen from the above figure, after the WHTE treatment of three LFM signals, cross items in the ρ-θ dimension are restricted, i.e., WHT has the capacity of restricting cross items as illustrated above. After the information entropy treatment, its performance is enhanced further so that it could efficiently reduce the influences of the cross item; meanwhile, SNRs before and after the WHTE treatment are calculated. After the WHTE treatment, the SNR of the LFM signal is increased averagely by about 11 dB, which is of great significance to realization of signal detection.

To expound further the performance of the algorithm, the method of the LFM signal linear frequency modulation put forward in [17] is adopted. The result is compared with the period WHT (PWHT) result and the similarity before and after signal separation is marked with the similarity factor to quantize the algorithm performance. The similarity factor ξ_{ij} of the separation signal and source signal are regarded as the performance index to evaluate separation effect, the definition of which [18] is as follows:

$$\xi_{ij} = \xi(s'_i, s_j) = \left| \frac{\sum_{t=1}^{k} s'_i(t) s_j(t)}{\sqrt{\sum_{t=1}^{N} s'^2_i(t) \sum_{t=1}^{N} s^2_j(t)}} \right|. \tag{22}$$

Before linear demodulation, the peak value is divided by multiplied dual weight and the similarity factor of the algorithm at different SNRs before and after the separation is obtained to describe the performance of the algorithm. The average similarity factor before and after the signal separation thus obtained is as shown in Fig. 5.

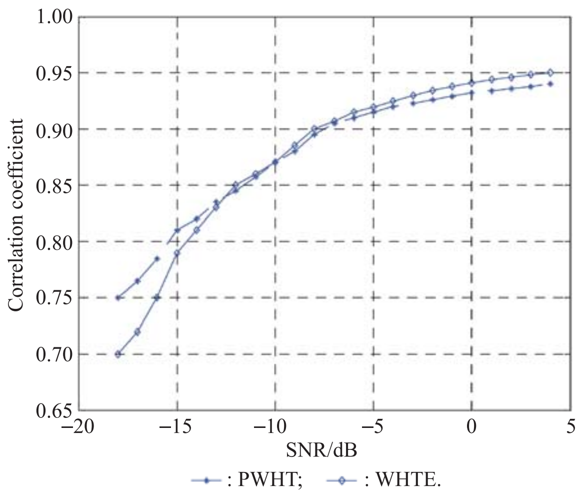


Fig. 5 Detection performances at different SNRs

Since the filter might have the information lost in demodulation and strong signals could hide weak signals, the separation performance of the signal is limited and the similarity factors of both could not reach 1. Though the signal detection performance of the WHTE detection algorithm is not so good as PWHT at low SNR, with the increase of SNR, the LFM detection and separation capacity of the WHTE could approach gradually the performance of the PWHT algorithm. Meanwhile, when conducting signal separation, filter should be designed based on the parameters of the PWHT signal, so the peak value of the PWHT separation performance is limited. However, the WHTE method is just to weight, which has no large influence on the LFM signal to be detected, so, the peak value of its similar coefficient is higher than the PWHT algorithm. Thus, it could be seen that the WHTE algorithm has strong LFM signal separation capacity at higher SNR and is with good applicability.

5. Conclusions

This paper combines the traditional WHT and the information entropy theory and illustrates the reasonability of the algorithm from the aspect of the information entropy theory. The LFM signal detection algorithm of the WHTE is also discussed by deducting the feasibility of the WHTE algorithm and the algorithm procedure of signal detection is also put forward.

All advantages of the algorithm adopted in this paper are illustrated theoretically. Identification and detection that are suitable for the LFM signal are verified by simulation. Meanwhile, the algorithm adopted in this paper is compared laterally with the existing algorithm and the computation complexity of the algorithm is analyzed briefly, from which it is concluded that the algorithm has better separation and expansion performance.

From the simulation, single signal detection probability and multiple signal identification performance could be obtained. The algorithm adopted in this paper could realize LFM signal identification at low SNR conditions. Moreover, with the increase of SNR, the detection performance could be improved significantly, which could restrict the influences of noises efficiently.

The algorithm adopted in this paper is improved based on the traditional WHT algorithm, whose performance is improved obviously compared with WHT and FrFT; compared with the improved PWHT algorithm, its performance is inferior; compared with the PWHT, the system performance of the algorithm could approach gradually PWHT with the increase of the treatment performance of the SNR without prior information. So, it could be said the algorithm has a good prospect of application and better performance of generalization.

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