# Research on Reducing Doppler Signal Time- frequency Distributed Speckles

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**Abstract:** Bigger noises and random fluctuations (forming Doppler speckles) are found in the Doppler signal spectra obtained from Short- time Fourier Transform (STFT) based on commercial Doppler analyzers. In order to reduce or inhibit these Doppler speckles, Wiener- Khintchine theorem is used to perform an auto correlation on the signal, reducing its electric noises and then conducting an Fourier Transform on the resulted signal with a Gaussian window function added to prevent the random fluctuations of spectrum. Finally better signal spectra are generated to reduce Doppler speckles.

**Key words:** Doppler speckle; auto correlation; window function
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# 针对减少多普勒信号时频分布斑点的研究

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摘要: 基于短时傅立叶变换(STFT)的商用多普勒分析仪所得出的多普勒信号谱存在较大的随机噪声和随机抖动(形成多普勒斑点); 为了减少或抑制这些多普勒斑点, 我们利用维纳辛钦定理先对信号进行自相关, 消除其电噪声, 然后再对去噪后的信号加上一个高斯窗函数做傅立叶变换抑制其谱的随机抖动, 最终得出了较好的信号谱形, 减少了多普勒斑点.

关键词: 多普勒斑点; 自相关; 窗函数

## 0 Introduction

Doppler ultrasound has become indispensable as a noninvasive tool for the diagnosis and management of cardiovascular diseases. The ultrasonic beams from moving erythrocyte will form Doppler ultrasonic (blood flow) signal, from which a series of diagnostic information and indexes are thus derived[1].

Short- time Fourier transform method(STFT) is a commonly used method to analyze Doppler signal. Currently, nearly all of the commercial Doppler analyzers rely on STFT based spectral analysis. However, the signal obtained from STFT has big random fluctuations, which results in granular shape, i.e., Doppler speckle, on the two dimensional time- frequency distribution graph- sonogram[2]. The formation of Doppler speckle is mainly caused by the random fluctuations of signal spectrum due to the strong interaction among the ultrasonic beams reflected from the erythrocyte with similar direction and velocity. Its existence greatly affects some signal- based medical parameters and indexes. For instance, it will make the real variation of signal spectrum become vague, which is unfavorable for the extraction of signal envelope and so on[3]. Therefore, the existence of Doppler speckle has been considered as one of the main defects of STFT[2].

As for Doppler speckle reduction, there are currently two methods under research: two- dimensional filtra-

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tion and ensemble average[4]. These two methods both can effectively reduce Doppler speckles, but each has its own defects and limitations, such as complicated calculation, poor real time and practicability. Therefore, another simple but technically mature method was tried in the present study: Wiener- Khintchine theorem plus window function was used to reduce Doppler signal time- frequency distributed speckles. It was found in the experiment that this method could better inhibit Doppler speckles and obtain smoother signal time- frequency distributed wave form.

## 1 Mathematical Background

### 1.1 The Short- Time Fourier Transform

Consider a signal $x(t)$, and assume it is stationary when seen through a window $W(t)$ centered at time location $\tau$, the Fourier transform of the windowed signal $X(t)W(t-\tau)$ is the short- time Foruier Transform (STFT):

$$X_\tau(f) = \int x(t)w(t-\tau)e^{-j2\pi ft}\mathrm{d}t \tag{1}$$

STFT maps the signal from time domain into a joint time- frequency plane $(\tau, f)$. For implementation, the discrete version of STFT should be used as

$$DX_n(k) = \sum_{i=n-\frac{N}{2}}^{i=n+\frac{N}{2}} x(i)w(i-n)e^{-j\frac{2\pi k}{N}} \tag{2}$$

Where $n$ and $k$ are the discrete time and frequency, respectively, and $N$ is the window length. The STFT - based time- frequency representation (energy distribution) of $x(i)$ is thus

$$SPEC(n,k) = |DX_n(k)|^2 \tag{3}$$

### 1.2 Wiener- Khintchine Theorem

Wiener- Khintchine theorem shows that the power spectrum density of stationary random signal is just the Fourier transform of its auto correlation function:

$$S_x(\omega) = \int_{-\infty}^{+\infty} R_x(\tau)e^{-j\omega\tau}\mathrm{d}\tau \tag{4}$$

where $R_x(\tau)$ is the auto correlation function of signal, $S_x(\omega)$ is the power spectrum density of signal. And the estimation of actual sampling auto correlation $\hat{R}_x(\tau)$ is:

$$\begin{cases} \hat{R}_x(\tau) = \dfrac{1}{N-|\tau|}\displaystyle\sum_{n=0}^{N-|\tau|-1} x(n)x^*(n+\tau) & \text{deviation- free estimation} \\ \hat{R}_x(\tau) = \dfrac{1}{N}\displaystyle\sum_{n=0}^{N-|\tau|-1} x(n)x^*(n+\tau) & \text{deviation estimation} \end{cases} \tag{5}$$

$N$ is the number of signal sampling points, $-N < \tau < N$.

For the convenience of calculation, the formula of deviation estimation was used to calculate the auto correlation sequence of signal. Since the process of auto correlation has a function of eliminating noises and centralizing signal energy, so that the wave form of signal can be smoothened to a certain degree.

### 1.3 Window Function

It can be understood from its principle that STFT actually intercepts signal by using a rectangle window function with the width equal to the quasi- smooth section of signal and then conducts a Fourier transform on the intercepted signal. Therefore, under the guideline of simple comparison, frequent use, easy calculation and realization, the Gaussian window function was selected to intercept the auto correlation of signal in the present study.

The time domain form of Gaussian window function is:

$$W(t) = \sqrt{\frac{\alpha}{\pi}}e^{-\alpha t^2} \tag{6}$$

In the present study, we choose $\alpha = 3$ because the Gaussian window function has the best compromise of time and frequency resolution when $\alpha = 3$[5].

## 2 Method

### 2.1 Generation and Treatment of Signal

Currently, the analysis of ultrasonic Doppler signal is usually conducted with a fixed- length time window and 10 ms is adopted, the signal within the interval is considered stationary[6]. In the present study, the sampling frequency of signal was 20 kHz and cardiac cycle was 1 s, so the actual sampling point in each section of quasi- stationary signal (10 ms) was 200.

As described in the introduction, Doppler speckles were formed by the interaction of the waves reflected from the erythrocyte in blood. This phenomenon of return wave interaction might be interpreted with the normal carotid unidirectional Doppler signal model established by Mo and Cobbold. In the model Doppler signal is supposed to be narrow band Gauss stochastic process, a group of sine functions with discrete frequency as $f_m$ ($m = 1, \cdots, M$, $[0, f_{max}]$ is divided into m sections at equal width could be used to simulate the signal:

$$x(t) = \sum_{m=1}^{M} a_m \cos(2\pi f_m t + \Phi) \tag{7}$$

where the random phase position $\Phi$ is evenly distributed on $[0, 2\pi]$ and $M$ is the number of sine wave; the detailed calculation can refer to the reference [6].

Mo and Cobbold model[7] was used to emulate over 100 Doppler blood flow signals with the maximum frequency from 1 350 Hz to 5 000 Hz. As to STFT, 10 ms rectangle window was used to intercept every 10 ms signal to calculate Doppler time- frequency distribution and sonogram of signal, for which each section was calculated at 200 points FFT with window signal added, the frequency interval was 20 kHz/200 = 100 Hz and 100 power spectra were calculated within 1s cardiac cycle.

### 2.2 Window Function and Its Length

The Gaussian window function was derived from the above mentioned window function formula. For a comparison with the method of STFT, window function was used to intercept the auto correlation of signal (after the signal was calculated with auto correlation, each section of 10 ms signal had 399 sampling points in even symmetry and the signal energy was accumulated on the center with the maximum value at $R_{xx}(0)$) at middle 200 points (i. e., number 101~ 300 auto correlated value), and then a Fourier transform was carried out to obtain the time- frequency distribution and sonogram of signal.

### 2.3 Apraisal of Performance

In the present study the normalized root- mean- square deviation of each set average power spectrum obtained with two different methods was taken as the basis of performance appraisal. Because this deviation represented the smooth degree of instantaneous power spectrum at each time, the smaller deviation showed that the spectrum was smoother and Doppler speckles were fewer.

The formula of normalized root- mean- square deviation is:

$$NRMSE = \sqrt{\sum_{i=1}^{100} \frac{\sum_{i=1}^{200} (X_i(t) - \bar{X}(t))^2}{\sum_{i=1}^{200} \bar{X}^2(t)}} \tag{8}$$

where $X_i(t)$ is the value of instantaneous power spectrum at each time and $\bar{X}(t)$ is the ensemble average power spectrum of each method.

## 3 Result and Discussion

Fig. 1 (a) shows the emulated Doppler signal time- frequency distribution (including 100 instantaneous power value) calculated with STFT within the entire cardiac cycle (1s); (b) shows the theoretical time – frequency distribution of Doppler signal (calculated with Mo and Cobbold model) within the cardiac cycle, which is all expressed in sonogram. It can be seen that the amplitude value of actual (emulated) Doppler blood flow signal changes greatly and the edge of signal spectrum wave form in the time – frequency graph is very uneven, so it is very difficult to find out clear envelope and plenty speckles (Doppler speckles) are formed, which is quite different form the theoretical spectra.

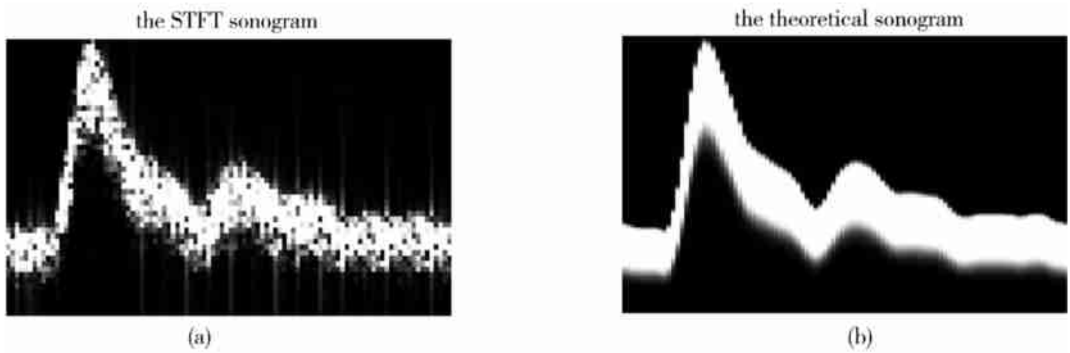


**Fig. 1 STFT and theoretical sonogtam**

Fig. 2 (a) shows a section of auto correlation function of emulated Doppler signal and the signal energy concentrates in the center after auto correlation; (b) shows a section of power spectra calculated from Wiener – Khintchine theorem (without window). Although it is very close to the spectra calculated with STFT, the obvious noises exist in the spectra obtained with STFT, while the spectra calculated with Wiener – Khintchine theorem are very smooth. This also verifies that the auto correlation process of signal itself plays a role in filtering noises and accumulating signal energy.

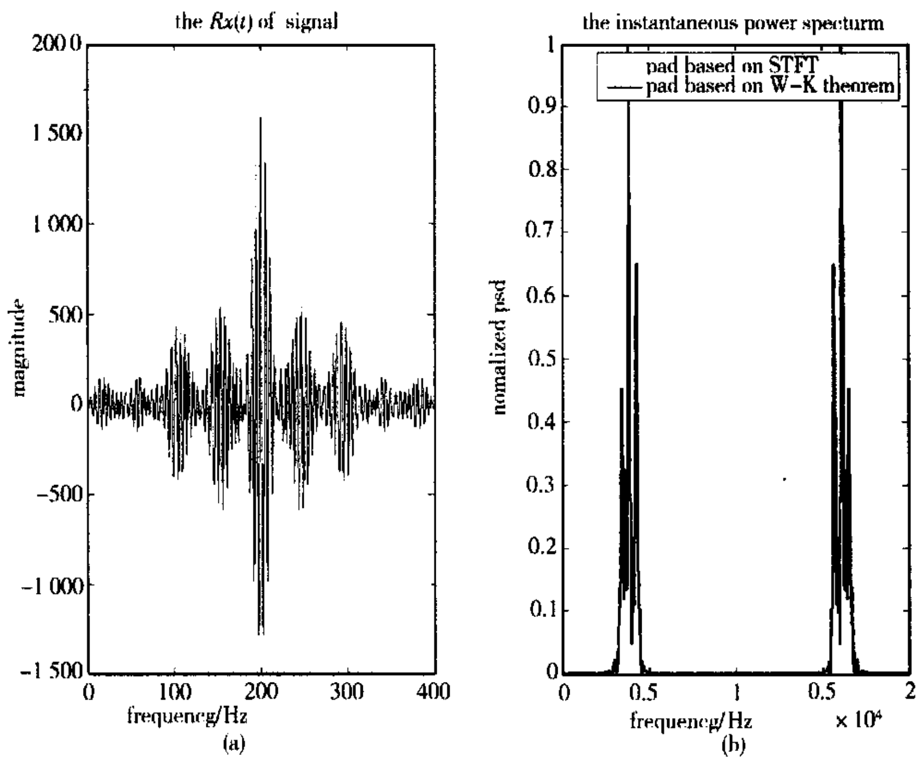


**Fig. 2 auto correlation of signel and instantaneaus psd**

Fig. 3 gives the instantaneous power spectra calculated at different time with different method in a cardiac cycle; plotted together for comparison are the instantaneous power spectra calculated with Wiener – khintchine theorem (intercepted with Gaussian window) and the power spectra obtained with STFT, in which (a) 25ms is in cardiac relaxing period and (b) 135ms in cardiac systole; it can be seen that the power spectra calculated from Wiener – Khintchine theorem with window function are really much smoother than those with STFT.

Fig. 4 shows the time – frequency distribution graph (sonogram) obtained with the same emulated Doppler signal intercepted with Wiener − Khintchine theorem plus window function; it can be seen that, compared with STFT, this new method better smoothens the time − frequency distributed wave form and reduce Doppler speckles. As described above, when the normalized root− mean − square deviation related to the set average power spectrum is used to compare the performance of the two methods, the following root − mean − square deviations are obtained: It can be seen from the figure that the deviations with Wiener− Khintchine theorem plus window function are much smaller than those with STFT, so this method has an obvious advantage over STFT in smoothening Doppler signal time− frequency distribution and reducing Doppler speckles.

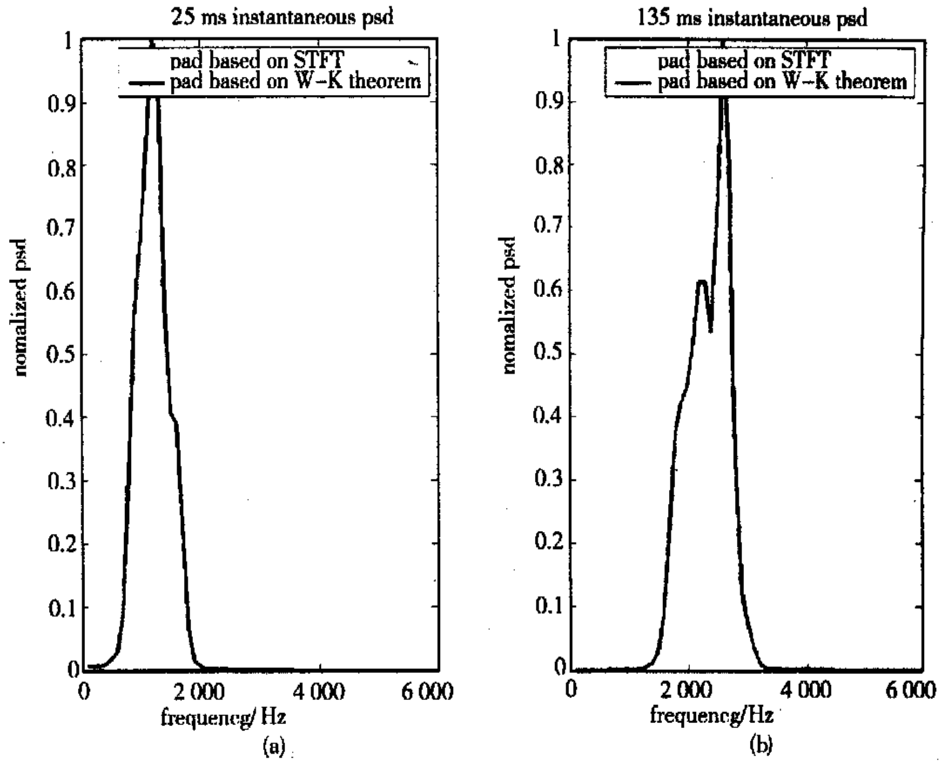


**Fig. 3 different time psd calculated with two methods**

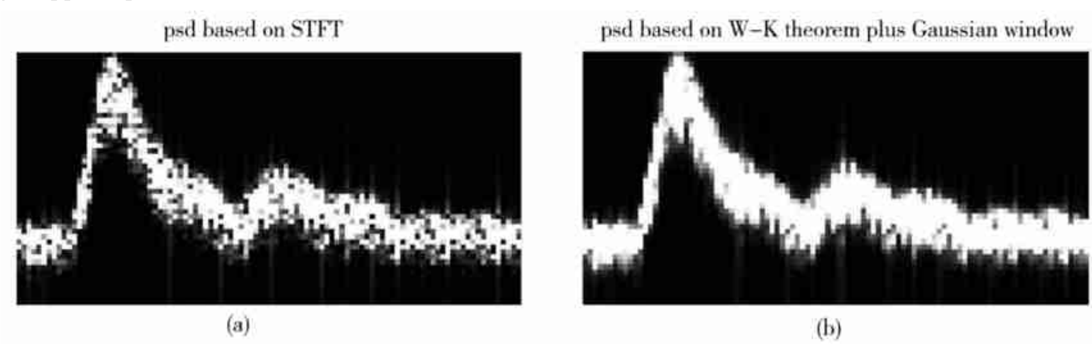


**Fig. 4 sonogram generated with two methods**

## 4 Conclusions

It can be drawn from the above that the present study conducted a spectrum analysis on the emulated Doppler signal with Wiener− Khintchine theorem plus window function, obtained the time− frequency distribution and sonogram of signal and compared it with the conventional and pure method of STFT with the purpose to smoothen Doppler signal time− frequency distributed wave form and reduce Doppler speckles. The findings prove that the quality of sonogram obtained with this method is much higher than that with STFT, so it is useful to extract such as spectrum envelope, calculate the power spectrum based medical quantitative indexes and help medical staff to diagnose dis-

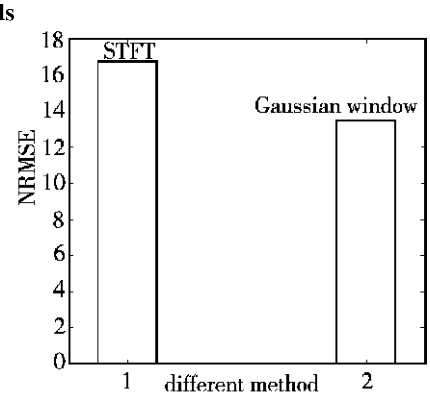


**Fig. 5 the NRMSE of two method**

eases.

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## 4 结 论

通过对遗传算法的学习和实验, 我们对基于遗传算法的最佳熵阈值图象分割算法有以下理解:

1) 基于最佳熵阈值的方法容易理解, 算法复杂度小.

2) 基于最佳熵阈值的方法能很好地对图象进行分割, 把图象中感兴趣的部分和背景区分开, 图象细节也能较好的保留, 如图2所示.

3) 用遗传算法分割图象能很好地提取出图象轮廓, 如图2所示.

4) 在设计适应度函数时算法用到了图象的先验信息. 设计适应度函数在遗传算法中是很重要的内容, 只有适应度函数正确的设计好, 算法最终才可能得到正确的解.

5) 遗传算法是迭代式的算法, 适用于并行计算, 这是它的处理策略.

6) 从计算费用上看, 由于遗传算法要经过许多代的演化才能搜索出最终结果, 又因为图象的数据量本身就很大, 所以算法的计算费用大, 这限制了该算法的实时应用. 但是, 随着计算机运行速度的提高, 而且由于遗传算法适合于并行计算, 这一缺陷将得到逐步克服.

7) 算法的预/后处理步骤少.

可以看出, 用遗传算法进行图象分割有其优点, 但也有缺点, 下一步的工作应该是进一步完善这一算法, 并考虑根据分割的图象提取物体的特征, 使得能够进行物体识别或图象理解.

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