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Denoising of radar signals by using wavelets and Doppler estimation by S-Transform

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ABSTRACT

The s-transform is a variable window of STFT and extension of wavelet. This paper discussed the principle and method of Wavelet De-noising, reduced noise of pulse signal based on wavelet. It is shown that wavelet de-noising can eliminate most noise, and preserve effectively sudden change of signal. This paper analyzed and compared the effect of de-noising of pulse signal in different ways all study shows de-noising of pulse signal based on wavelet have practical value. From the s-transform the Doppler frequency can be estimated in different ways.

Keywords: STFT, wavelet, Radar micro-Doppler effect, Doppler estimation, S-transform, Time-frequency analysis, Window function.

I. INTRODUCTION

The *S*-transform is a time-frequency spectral localization method, similar to the short-time Fourier transform (STFT), but with a gaussian window whose width scales inversely, and whose height scales linearly, with the frequency The expression of the *S*-transform given by Stockwell is

$$S(\tau, f) = \int_{-\infty}^{\infty} h(t) \left\{ \frac{|f|}{\sqrt{2\pi}} \times \exp\left[\frac{-f^2(\tau - t)^2}{2}\right] \exp(-2\pi i f t) \right\} dt. \quad (1)$$

In equation (1), *S* denotes the *S*-transform of *h*, which is a continuous function of time *t*; frequency is denoted by *f* ; and the quantity ¿ is a parameter which controls the position of the Gaussian window on the *t*-axis. The scaling property of the Gaussian window is reminiscent of the scaling property of continuous wavelets because one wavelength of the Fourier frequency is always equal to one standard deviation of the window. The S-transform, however, is not a wavelet transform, because the oscillatory parts of the S-transform “wavelet” [the term in braces in equation (1)] is provided by the complex Fourier sinusoid, which does not translate with the gaussian window when τ is changed. As a result, the shapes of the real and imaginary parts of the s-transform “wavelet” change as the gaussian window translate in time. True wavelets do not have this property because their entire waveform translates in time with no change in shape. Thus, the s-transform is conceptually a hybrid of short-time Fourier analysis and wavelet analysis, containing elements of both but falling entirely into neither category. The S-transform has an advantage in that it provides multi resolution analysis while retaining the absolute phase of each frequency. This has led to its application for detection and interpretation of events in time series in a variety of disciplines. Micro-Doppler effect in mathematics can be expressed as the joint function of time and frequency because of the relation between micro-Doppler frequency and time. The Fourier transform (FT) is one of the most widely used methods in signal analysis and processing. However ,it should be noted that the FT can only provide the overall frequency information in analyzed signals, which does not describe the local frequency spectrum over short periods of time. Therefore, the FT is not suitable for analysis of micro-Doppler signals. While the time-frequency analysis is useful to represent two-dimensional time-frequency distribution of time and frequency information in signals, the characteristics of time-varying frequency in micro-Doppler signals can be extracted and showed by the joint time-frequency analysis. The STFT is one of classical time-frequency transforms. Because the moving window with constant shape and width is adopted in the STFT, the resolution for time-dependent frequency analysis is limited. The deficiency in the WVD is against its application in multi-component signal analysis. The CWT is on the basis of joint time-scale fundamental mother wavelet. Although it could achieve multi-resolution in time-frequency domain by width-varying window according to the frequency, the CWT is limited in time-frequency analysis due to the admissibility condition in wavelet theory and a large computational burden in application. By the combination of the STFT and the CWT, R.G. Stockwell proposed a time-frequency spectral localizing method with the product of harmonic wave function and Gaussian window function as the mother wavelet. This is called the S transform (ST).

II. WAVELET

A wavelet is a *small wave* which oscillates and decays in the time domain. As discerning readers must have noticed, the logo of *Resonance* resembles a wavelet quite well. Unlike the Fourier transform, wavelets can have infinite varieties which are fundamentally different from each other. The ones which have strictly finite extent in the time domain, are known as *discrete wavelets*, otherwise they go by the name of *continuous wavelets*. A wavelet basis set starts with two orthogonal functions: the *scaling function* or *father wavelet* $\phi(t)$ and the *wavelet function* or *mother wavelet* $\psi(t)$, by scaling and translation of these two orthogonal functions we obtain a complete basis set.

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The scaling and wavelet functions, respectively, satisfy

$$\int_{-\infty}^{\infty} \phi(t)dt = A \quad \& \quad \int_{-\infty}^{\infty} \psi(t)dt = 0$$

where A is a constant. The energies of these functions are finite, which means

$$\int_{-\infty}^{\infty} |\phi(t)|^2 dt < \infty \quad \& \quad \int_{-\infty}^{\infty} |\psi(t)|^2 dt < \infty$$

The scaling function and the mother wavelet are orthogonal to each other:

$$\int_{-\infty}^{\infty} \phi^*(t)\psi(t)dt = 0$$

From above equation, it is apparent that $\psi(t)$ resembles a wave which is localized in time, in other words it is a small wave or a *wavelet.* In a given wavelet basis set, there is only one scaling function; the rest of the elements are the wavelets. Starting from the mother wavelet, one derives the *thinner* daughter wavelets by appropriate amount of scaling. Scaling is an operation which makes a given object thicker or thinner, by the choice of a parameter. When combined with translation, by amounts commensurate with the size of the wavelets at various scales, one obtains a complete orthogonal basis set, where each element has a finite size.

III. S-TRANSFORM

The S-transform is a time-frequency analysis technique proposed by Mansinha et al. combines both properties of the short time Fourier transform and wavelet transform. It provides frequency dependent resolution while maintaining a direct relationship with the Fourier spectrum. The S-Transform of a signal x(t) is defined as

$$S(\tau, f) = \int_{-\infty}^{\infty} x(t)w(\tau - t)e^{-j2\pi f t}dt \qquad (1)$$

Where the window function is a scalable Gaussian window

$$w(t, \sigma) = \frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{t^2}{2\sigma^2}} \qquad (2)$$

And

$$\sigma(f) = \frac{1}{|f|} \qquad (3)$$

Combining equation (2) and (3) gives

$$S(\tau, f) = \int_{-\infty}^{\infty} x(t)\left\{\frac{|f|}{\sqrt{2\pi}} e^{-\frac{(\tau-t)^2 f^2}{2}} e^{-j2\pi f t}\right\} dt \qquad (4)$$

The advantage of S-transform over the short time Fourier transform is that the standard deviation σ (f) (window width) is a function of f rather than a fixed one as in STFT. In contrast to wavelet analysis the S-Transform wavelet is divided into two parts as shown within the braces of equation(4).One is the slowly varying envelope (the Gaussian window) which localizes the time and the other is the oscillatory exponential kernel $e^{-j2\pi f t}$ which selects the frequency being localized. It is the time localizing Gaussian that is translated while keeping the oscillatory exponential kernel stationary which is different from the wavelet kernel. As the oscillatory exponential kernel is not translating, it localizes the real and the imaginary components of the spectrum independently, localizing the phase as well as amplitudespectrum.

Thus it retains absolute phase of the signal which is not provided by Wavelet Transform. The standard S-Transform provides unnecessary restrictions on the window function used. In fact the Gaussian window has no parameter to allow its width in time or frequency to be adjusted.

DOPPLER ESTIMATION

Noise is discriminated from targets by the variation in the radial velocity and amplitude over successive measurements. Consistency tests are applied to the measurements based on the assumption that clutter and noise will fluctuate in both amplitude and estimated doppler over successive measurements; but moving targets generally will not.

TABLE 1

Comparison of PSNR and MSE with input SNR

Input SNR	Output PSNR	MSE
2	49.9095	0.6639
5	50.2008	0.6209
8	50.3842	0.5952
10	50.3990	0.5932
15	50.5895	0.5677
20	50.6150	0.5644
25	50.6640	0.5581

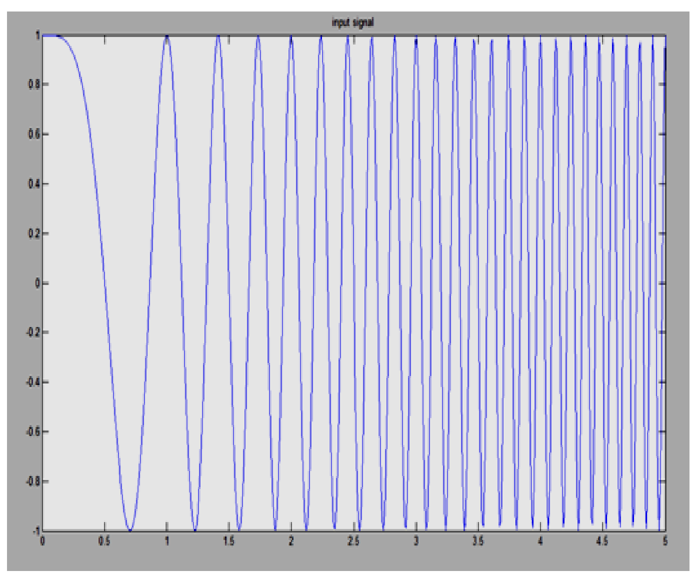

Fig1:Input LFM signal

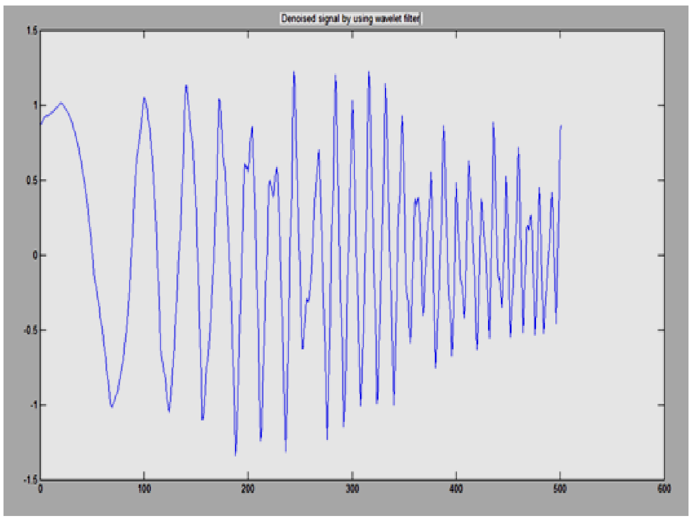

Fig2: the wavelet transformed for input LFM signal

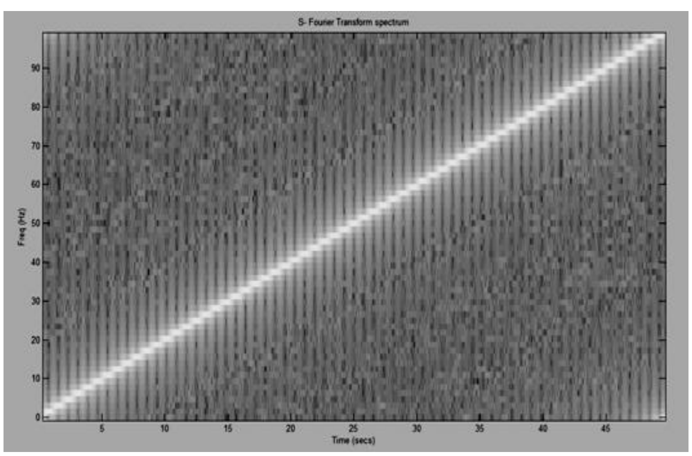

Fig3: S-Transformed waveform of the wavelet

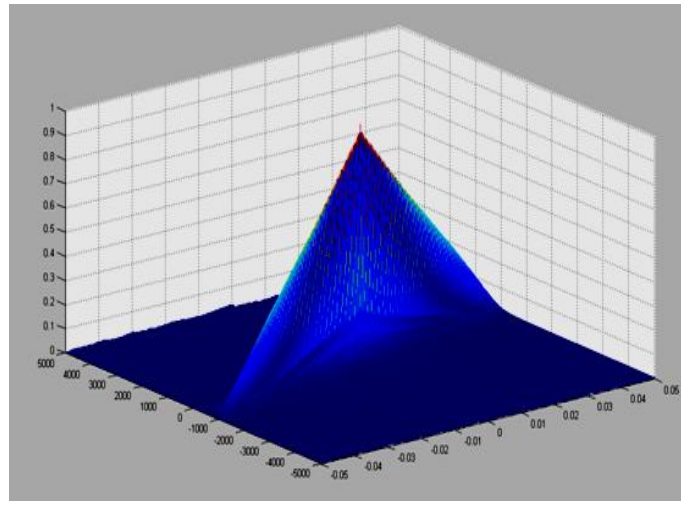

Fig4: Ambiguity diagram for S-Transformed signal

IV. CONCLUSION

In this paper we have proposed an S-Transform for the doppler estimation of the radar signal. This has been achieved by introducing a modified Gaussian window which scales with the frequency in an efficient manner such that it provides improved energy concentration of the S-Transform. The effective variation of the width of the Gaussian window has a better control over the energy concentration of the S-Transform. This has been possible by introducing an additional parameter (δ) in the window which varies with frequency and thereby modulates the S-Transform kernel efficiently with the progress of frequency. The proposed scheme is evaluated and compared with the standard S-transform and STFT by using a set of synthetic test signals. The comparison shows that the proposed method is superior to the standard one as well as STFT providing a better time and frequency resolution.

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