An analysis of X-band Radar Micro-Doppler Signature on Typical Ground Targets using S-Distribution

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Abstract

The micro-Doppler signature of a target can provide more information for target classification and recognition . Battlefield surveillance radar has low Doppler resolution, which provide coarse micro-Doppler signature. In order to get more detailed micro-Doppler signature, high-resolution time-frequency distribution is necessary. In this paper, we use S-Wigner distribution(SWD), compared with STFT, to analysis the micro-Doppler signature of vibratory and three typical ground targets in battlefield.

1. Introduction

Since the improvement of the ability of radar's measurement and the level of digital signal processing, the states of a target are expected to be described in specific details. The analysis of micro-motion on a target made them achieved. It frequently occurs that a target or some structure on the target is vibrating, rotating, tumbling, precession and some other micro-motions besides the target's translation. When radar transmits a signal to a target, caused by these micro-motions, the additional frequency modulations on the returned radar signal, which generate sidebands about the target's Doppler frequency may be induced, called the micro-Doppler effect[1]. Considering the uniqueness of micro-Doppler features for various targets, the analysis of radar micro-Doppler signature, often being encountered in civilian and military applications, is possible used for target recognition and classification. The micro-Doppler effect is originally introduced in coherent laser radar systems by V.C. Chen and H. Ling [2,3]. The whole variety of tools for time-frequency analysis, mainly rendered in the form of energy distribution in the time-frequency plane, has been proposed[4,5]. STFT is the oldest and the most widely used method for time frequency signal analysis, which is based on a straightforward extension of the Fourier transform, by using a window function to extract the signal's spectral content at and around a given time instant[6]. It belongs to linear signal transformations, but it provides a low time frequency resolution and concentration. The Wigner-Ville distribution(WVD) is a bilinear time frequency distribution. Although it produces a good time frequency resolution, it suffers cross-term interference, which is harmful to the radar returned signal. To improve distribution concentration, the time frequency distributions with high orders is proposed, e.g, polynomial Wigner distribution and L-class of distribution. Although these distributions are closely related to the time varying higher order spectra, they do not preserve the usual marginal properties[7,8].

In this paper, a method for the efficient realization s-class of time frequency distribution, which may achieve high concentration at the instantaneous frequency and resolution, is presented. The S-distribution can satisfy both time marginal as well as the frequency marginal in the case of asymptotic signals, and unbiased energy conditions. Also, the experiment based on this method is completed.

2. Basic mathematical description of the SWD

S-Wigner distribution, which is proposed by Stankovic after L-Wigner distribution, can improve distribution concentration. The scaled variant of the L-Wigner distribution of a signal $x(t)$ is defined by References[5].

$$SD_L(t,\omega) = \int_\tau x^{[L]}\left(t+\frac{\tau}{2L}\right)x^{[L]*}\left(t-\frac{\tau}{2L}\right)e^{-j\omega\tau}d\tau \tag{1}$$

where $x^L(t)$ is the modification of $x(t)$ obtained by multiplying the phase function by L , while keeping the amplitude unchanged.

For simulation, iterative method can be applied to calculate SWD. A recursive method, called S-method, is proposed to reduce the cross-terms as well as avoiding oversampling by using a smooth window in the frequency domain[6].The formula of the iteration is given by eqn.2 and eqn.3,

$$SW_1(t,\omega)=\frac{1}{\pi}\int_{-\infty}^{\infty}P(\theta)F(t,\omega+\theta)F^{(n)*}(t,\omega-\theta)d\theta \tag{2}$$

$$SW_{2L}(t,\omega)=\frac{1}{\pi}\int_{-\infty}^{\infty}P(\theta)SW_L(t,\omega+\theta)SW_L^{(n)}(t,\omega-\theta)d\theta \tag{3}$$

where $P(\theta)$ is a frequency domain window function, which has to be wide enough to ensure the integration over auto-terms and narrow enough to avoid cross-terms. $F(t,\omega)$ is the short time Fourier transform, $F^{(n)}(t,\omega)$ is an amplitude normalized version of $F(t,\omega)$, if the signal is multicomponent, and it is assumed that $x(t)=\sum_{i=1}^{l}x_i(t)$, then $F^{(n)}(t,\omega)$ is defined as

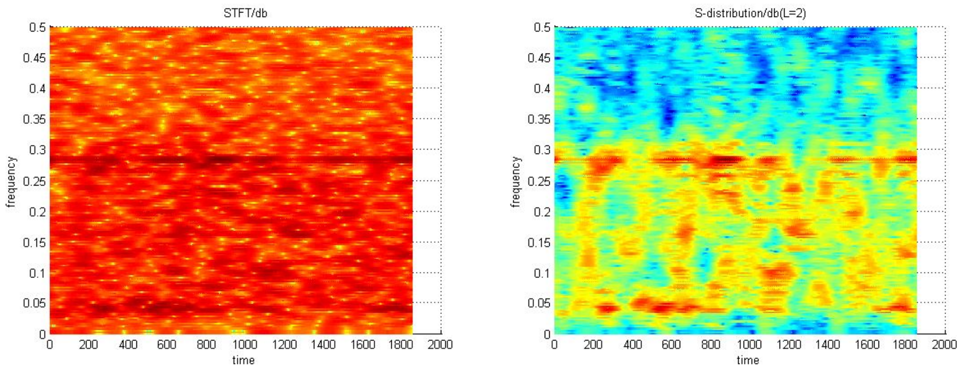
$$F^{(n)}(t,\omega)=\sum_{i=1}^{l}\Pi_{\Omega_i}(\omega)F(t,\omega)\sqrt{\frac{E_h}{E_{x_i(t)}}} \tag{4}$$

where $\Pi_{\Omega_i}(\omega)$ is a function which has only two values, unity for ω inside Ω_i and zero outside. E_h is the energy of the time domain window, which is used in the STFT, $E_{x(t)}$ is the energy of the signal component. Thus, the S-distribution for $L=1$ can be realized easily by the eqn.5. According to eqn.6. Also from eqn.3, the SWD for $L=4,8,\cdots$ can be known. Obviously, this procedure can be continued up to any order of the S-distribution.

3. Simulation Study Result Analysis

In this section, experimental trials are conducted to investigate and resolve the micro-Doppler radar signatures of targets using an X-band radar. Three types of data collection are performed to verify the conclusion in the front section. The targets used in the experiment are a driving creeper truck and a walking man.

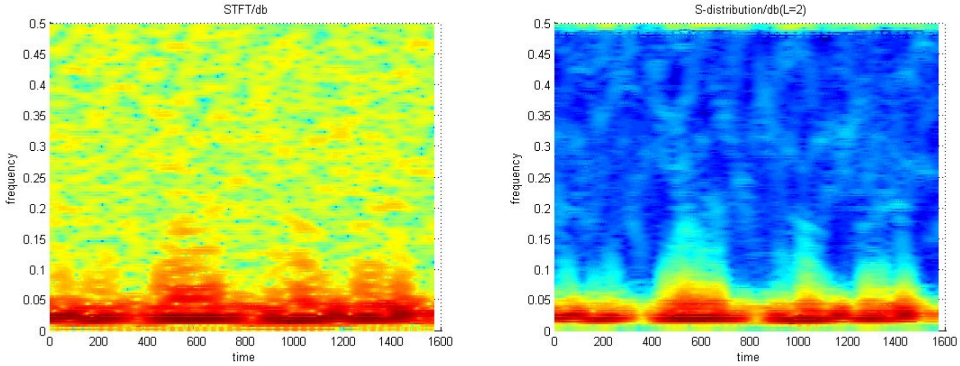
The result of a driving creeper truck is shown in figure 1. In this experimental, the creeper truck moves nearly straightly at a constant speed. As to figure 1, the STFT of the original radar returned data from a creeper truck driving straightly is computed and the image obtained is shown in fig.1(a), while the SWD of the signal is in fig.1(b). The micro-motion signature can rarely be seen from the picture. The reason is that the component of the creeper truck does not move separately, there hardly exists micro-motion in this experimental. However, the translational motion can be seen clearly in the picture. Since the track of the creeper truck has a better reflex ability for the microwave than the wheel of the creeper, the translational motion feature of the creeper truck presents wide to some extent.



(a) (b)

Figure 1. Analysis result for a creeper truck

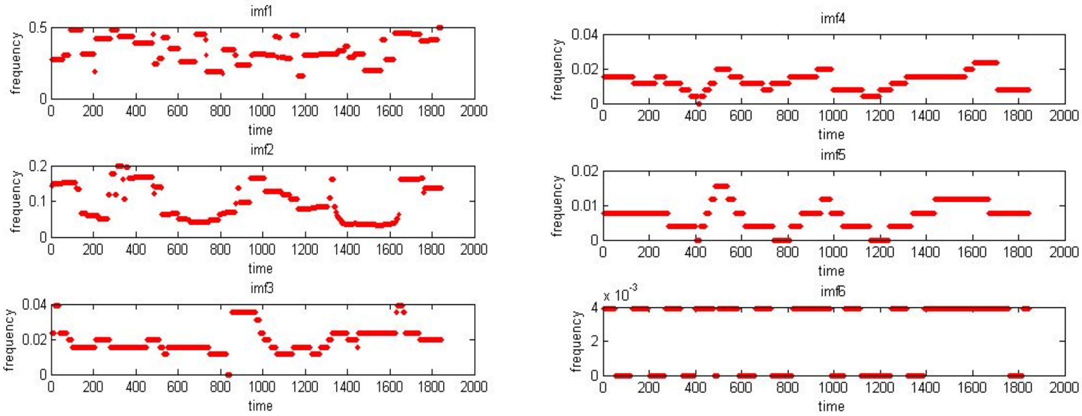
Experimental human data is used in the analysis of micro-Doppler signal in fig.2, the fig.2(a) shows the result gained by the STFT while the fig.2(b) shows the result gotten by the SWD. The man participating in the test is a soldier, who walks along a invariable direction at almost invariable speed. It is obviously that the human gait is a complex motion which comprised many movements of individual body parts. These moving body parts are the structures that exhibit unique micro-Doppler signatures suitable for target recognition[8]. As shown in figure 2, a human when he is walking, his body's time-frequency signature presents sine wave.



(a) (b)

Figure 2. micro-Doppler analysis for a man

Further on, in order to analyze the feature of human moving, EMD(Empirical Mode Decomposition) method is used. Using EMD arithmetic to decompose signal is based on the signal's different frequency. So a human's different frequency micro-motion can be decomposed by this method. The decomposition result is shown in figure 3 as follow. The imf1 in fig3(a) describes the background noise, because of its mean distribution characteristic. The imf2 in fig3(a) presents the moving of a man's feet and shank, which have a fast moving frequency. The imf3 in fig3(a) expresses the moving of a man's forearm, the imf4~imf6 in fig3(b) shows partly the movement of thigh, big arm, trunk.



(a) (b)

Figure 3. The decomposition of a human's micro-motion feature

The micro-motion feature can be analyzed by using time-frequency analysis method both STFT and SWD. It provides a better time frequency resolution and concentration by using the SWD, compared with the STFT. Besides, the SWD reduces the noise surround dramatically, the SNR is significantly enhanced after SWD extraction as compared to the STFT extraction.

4. Conclusion

With the help of SWD, the micro-Doppler feature in the time-frequency plane can be well displayed. The method for the efficient realization s-class of time frequency distribution is proposed. Theory is proved by the simulation to the target with vibration. Then, the characteristics of the micro-Doppler signatures for the two types of ground target are analyzed, based on the SWD. In order to improve the time frequency concentration, the order of the SWD can be increased, which brings out the reduced energy distribution yet. By simulation and comparative analysis, it is demonstrated that SWD is effective in the micro-Doppler analysis, especially when there is noise existed. Furthermore, the length of frequency domain window can influence the final effect.

5. References

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