Progress In Electromagnetics Research, PIER 74, 309–317, 2007

MULTIPLE TARGETS DETECTION METHOD BASED ON BINARY HOUGH TRANSFORM AND ADAPTIVE TIME-FREQUENCY FILTERING

Xue W. † **and Sun X.-W.**

Shanghai Institute of Microsystem and Information Technology
Chinese Academy of Sciences
Shanghai, 200050, China

Abstract—When the echo energy of multiple targets of vehicle volume detecting radar diverge greatly, small targets are easily masked by the platform of large targets, it is difficult to detect the all the targets by the Wigner-Hough Transform simultaneously. In this paper, a method based on binary Hough Transform and adaptive time-frequency filtering is proposed, which can avoid the problems of detecting the platform of large targets as well as platform masking of small targets and detect all the targets with different energy at the same time. The experimental results show the method has good performance and high practical value.

1. INTRODUCTION

In vehicle volume detecting radar, the IF signals contain target signal and disturbances, the target signal is approximately the LFM signal, so the detection of target can be regarded as the detection of LFM signal in noise background. The Wigner-Ville Distribution (WVD) [1] has high time-frequency concentration and is usually used to detect LFM signal, but because it is bilinear, it brings cross terms when applied to multiple LFM signals, which degrades the performance of detection. Utilizing the property in the detecting lines of Hough Transform, the Wigner-Hough Transform (WHT) [2, 3] can suppress the cross terms and estimate parameter of signals, while when the energy of multiple targets diverge greatly, small targets are easily masked by the platform of large targets, it is difficult to detect the all the targets by the WHT at the same time. The "CLEAN" technique [4–7] can separate every

† Also with Graduate School of Chinese Academy of Sciences, Beijing, China.

target step by step to solve the problem, but the technique need to perform the WHT several times and the burden of computation is very large.

In this paper a method based on binary Hough Transform and adaptive time-frequency filtering is proposed. The method first performs the binary processing of the WVD of signals, then the WVD is mapped to Hough space, which makes small targets and large targets look the same energy in Hough space, at last the adaptive time-frequency filtering is used for the more suppression of noise and cross terms. The experimental results show the method can detect multiple targets with diverse energy at the same time and has high practical value.

2. PRINCIPLE OF VEHICLE VOLUME DETECTING RADAR

FMCW radar [8] has been widely applied to measure range and velocity of target [9–11], the vehicle volume detecting radar adopts the FMCW system, it consists of RF module, IF filter and DSP module, the system block diagram of the radar is shown in Fig. 1, the frequency of emitted signal is modulated by a triangular signal and the center frequency of emitted signal is 24 GHz.

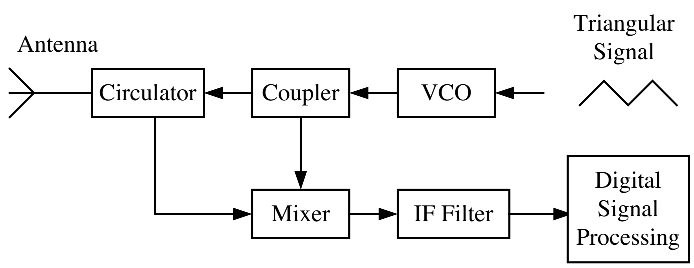

Figure 1. System block diagram of vehicle volume detecting radar.

The IF signals of the radar is expressed as:

$$S(t) = A\cos 2\pi\left(f_0\tau + \frac{2\Delta F}{T}t\cdot\tau - \frac{\Delta F}{T}\tau^2\right) \tag{1}$$

Where f_0 is the carrier frequency, T is the period of the triangular signal, C is the velocity of light, ΔF is the modulated bandwidth, $\tau = \frac{2R}{C}$ is the time delay, the difference frequency corresponding to the target is:

$$f = \frac{4\Delta FR}{CT} \tag{2}$$

In practice, the radar is fixed on a pole standing on the side of lanes, so that the radar can cover multiple lanes. Because the distances of targets in different lanes to radar are different, therefore the targets in different lanes correspond to different frequency range. When there is a car passing the detecting area in a lane, the energy of corresponding IF signals would enhance, the vehicle volume of the lane can be detected through analyzing the variation of energy of the IF signals. Because the echo energy of target is proportional to its radar cross section (RCS) [12], when multiple targets with diverse RCS pass the detecting area in different lanes simultaneously, the energy of IF signals corresponding to the targets diverge greatly, it is important for the detection to judge all the targets accurately.

3. PRINCIPLES OF BINARY HOUGH TRANSFORM AND ADAPTIVE TIME-FREQUENCY FILTERING

3.1. Wigner-Hough Transform

The WVD of a signal $s(t)$ is defined as:

$$W_S(t,f) = \int_{-\infty}^{+\infty} s(t+\tau/2)s^*(t-\tau/2)e^{-j2\pi f\tau}d\tau \tag{3}$$

The WVD has high resolution for single signal, but in the case of multiple signals, it brings cross terms, the presence of cross terms can seriously impair the capability of detecting the signal parameters.

For a LFM signal $s(t) = \exp[j2\pi(ft + \frac{1}{2}gt^2)]$, its WVD produces a distribution of the energy concentrated along a line $v = f + gt$, the problem of detecting a LFM signal can he interpreted as the problem of detecting a linear pattern in the time-frequency plane.

The Hough Transform (HT) [13] is usually used to detect lines. In the time-frequency plane, the parametric equation of a line can be expressed as:

$$\rho = x\cos\theta + y\sin\theta \tag{4}$$

Where ρ is the distance from the origin to the line, θ is the angle between the normal to the line and the t axis. The points in the (t, f) plane are mapped to the (ρ, θ) space by (4), each point corresponds to a sine curve. If there are n points in a certain line, they correspond to n sine curves, all the curves intersect in a point whose location corresponds to the parameters of the line, a peak will occur at the point by the line integration. The HT changes the detection of line in the time-frequency plane into the detection of peak in the parameter space

The WHT combines the WVD and the HT, it can be interpreted as a line integral of the WVD in the parameter space, the WHT of $s(t)$ is given by [3]:

$$\begin{aligned} WH_S(f,g) &= \int_{-\infty}^{+\infty}\int_{-\infty}^{+\infty} W_s(t,v)\delta(v-f-gt)dtdv \\ &= \int_{-\infty}^{+\infty} W_S(t,f+gt)dt \end{aligned} \tag{5}$$

The parameters corresponding to $s(t)$ are:

$$g = -\cot\theta, \qquad f = \rho/\sin\theta \tag{6}$$

It can be seen that if $s(t)$ is a LFM signal with parameters f and g, there is a peak corresponding to the LFM signal in the parameter space by the WHT.

3.2. Binary Hough Transform

The WHT can suppress the cross terms and improve the performance of detecting multiple LFM signals. When the energy of multiple signals diverge little, the WHT has good performance, while the energy of multiple signals diverge greatly, small targets are easily masked by the platform of large targets, it is difficult to set a threshold to detect all the targets in the parameter space.

One way of solving the problem is to use "CLEAN" technique, but it requires more computation. In the paper, the binary Hough Transform [14] is proposed to alleviate the problem. The fundamental principle of binary Hough Transform based on WVD is: the WVD of multiple signals is computed first, then a primary threshold η is set in the time-frequency plane, the value of point whose amplitude is higher than η is defined as 1, the value of point whose amplitude is lower than $-\eta$ is defined as -1, the value of point whose amplitude is between $-\eta$ and η is defined as 0. Then only the points whose values are 1 or -1 are mapped to the parameter space and integrated, when the value of integration exceeds the second threshold μ in the parameter space, a target is thought to be detected. The binary Hough Transform makes small targets and large targets look the same energy in the parameter space, which can solve the problem of the platform of large targets masking the peaks of small targets and helps to detect the small targets.

3.3. Adaptive Time-Frequency Filtering

Adaptive time-frequency filtering [15] exploits the priori knowledge of auto term, cross term and noise properties to increase the SNR. The filtering consists of two parts: 1) distinguishing signal-rich and signal-poor regions of the time-frequency plane; 2) applying a smoothing or masking function to enhance the desirable signal. For multiple LFM signals, the SNR can be improved by setting the confidence weights proportional to amplitude of WHT. One simple way is to give different weights to $WH_S(\rho,\theta)$ with respect to different ρ, if there is a LFM signal with respect to a certain ρ, the $WH_S(\rho,\theta)$ with respect to the ρ should be given great weight. The ratio of the maximum $WH_S(\rho,\theta)$ with respect to different ρ to the global maximum $WH_S(\rho,\theta)$ should be computed first, the adaptive weight is defined as:

$$f_m(\rho) = \left(\frac{\max\limits_{\theta}\left[WH_S(\rho,\theta)\right]}{\max\limits_{\rho}\left\{\max\limits_{\theta}\left[WH_S(\rho,\theta)\right]\right\}} \right)^{\beta} \tag{7}$$

where β is the parameter that controls the strength of the adaptability. If $\beta \gg 1$, the weights are very small other than the ρ corresponding to the most powerful LFM signal, which would suppress other LFM signals; if $\beta \ll 1$, all the weights would be close to 1 and little adaptability occurs. Empirically, the value of β is usually chosen to be 0.5.

4. EXPERIMENTAL RESULTS

In the experiment, the sampling rate is 500 KHz, the number of sample is 512. When there is a car passing the detecting area in a lane, the WVD of IF signals produces a distribution of the energy concentrated along a straight line corresponding to the difference frequency of target, because the difference frequency of target is approximately constant during a sampling period, the line can be regarded as a LFM signal with zero sweep rate.

Fig. 2 shows the WVD of IF signals that are sampled when there are two cars with different RCS passing the detecting area in lane 1 and lane 4 simultaneously. It can be seen that the energy distributions corresponding to large target and cross terms are obvious, while the energy distribution corresponding to small target is quite weak.

Fig. 3 shows the Hough Transform of the WVD of the sampled IF signals. It can be seen that the peak of large target is very large, while the peak of small target is masked by the platform of large target. If we choose a threshold low enough to detect the small target, we risk

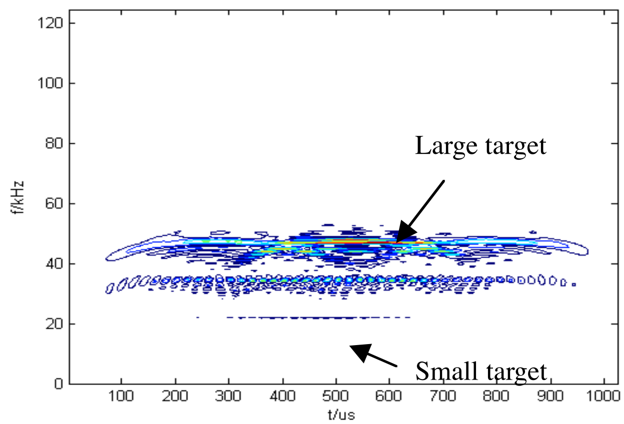

Figure 2. The WVD of sampled IF signals.

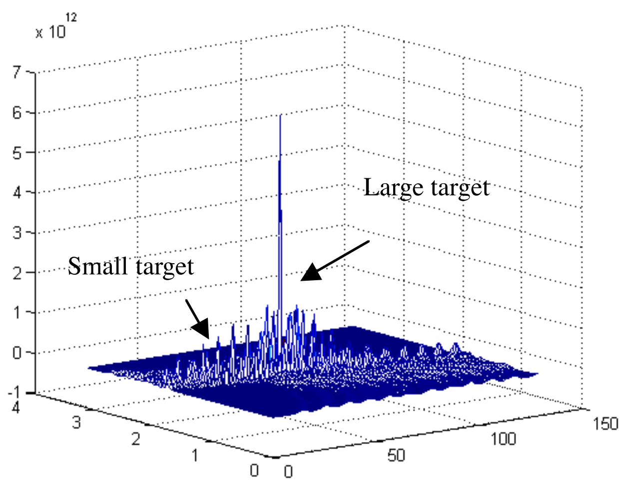

Figure 3. Hough Transform of the WVD.

detecting the whole platform of the large target; but if we choose a threshold above the platform of the large target, we risk missing the small target, it is difficult to set a threshold that allows detecting small target and avoids detecting large target platform.

Fig. 4 shows the binary Hough Transform of the WVD of the sampled IF signals. It can be seen that the relative energy of small target has been increased and the peaks of large and small target are

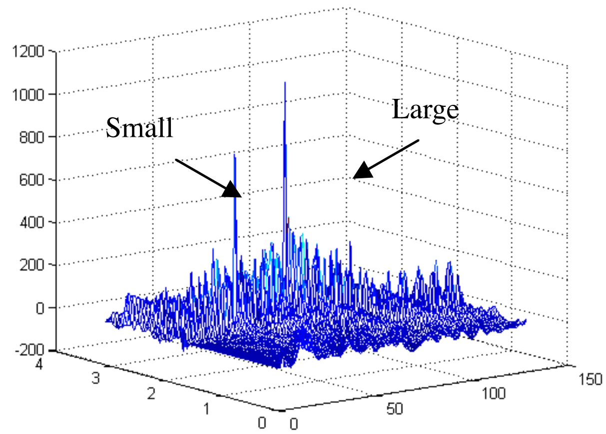

Figure 4. Binary Hough Transform of the WVD.

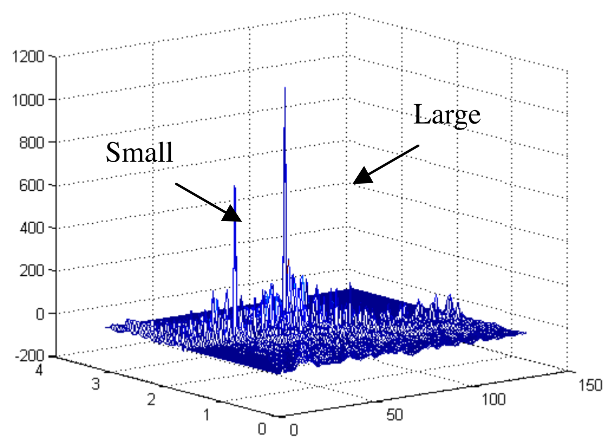

Figure 5. Adaptive time-frequency filtering for the binary Hough Transform of the WVD.

distinguishable in the parameter space, while at the same time the relative energy of noise and cross terms also has been increased because of the binary processing.

Fig. 5 shows the results of adaptive time-frequency filtering for the binary Hough Transform of the WVD. It can be seen that the filtering provides more suppression for the noise and cross terms and makes the peaks of targets more clear. The performance of detection can be improved effectively by the filtering.

5. CONCLUSION

When the energy of multiple targets of vehicle volume detecting radar diverge greatly, it is difficult to detect all the targets at the same time by the WHT. A method based on binary Hough Transform and adaptive time-frequency filtering is proposed in this paper, it can solve the problem of the platform of large targets masking the peaks of small targets effectively and detect all the targets simultaneously. Experimental results show the method has good performance for the multiple targets detection.

REFERENCES

1. Cohen, L., "Time-frequency distributions — a review," *Proceeding of the IEEE*, Vol. 77, No. 7, 941–981, 1989.
2. Barbarossa, S. and A. Zanalda, "A combined Wigner-Ville and Hough transform for cross terms suppression and optimal detection and parameter estimation," *ICASSP'92*, Vol. 5, 173–176, 1992.
3. Barbarossa, S., "Analysis of multicomponent LFM signals by a combined Wigner-Hough transform," *IEEE Trans. Signal Processing*, Vol. 43, 1511–1515, June 1995.
4. Tsao, J. and B. D. Steinberg, "Reduction of side lobe and speckle artifacts in microwave imaging: the CLEAN technique," *IEEE Transaction on Antennas and Propagation*, Vol. 36, No. 4, 543–556, 1988.
5. Bao, Z., G. Y. Wang, and L. Luo, "Inverse synthetic aperture radar imaging of maneuvering targets," *Optical Engineering*, Vol. 37, No. 5, 1582–1588, 1998.
6. Choi, I. S., D. K. Seo, J. K. Bang, H. T. Kim, and E. J. Rothwell, "Radar target recognition using one dimensional evolutionary programming based clean," *Journal of Electromagnetic Wave and Application*, Vol. 17, 763–784, 2003.
7. Camps, A., J. Bar'a, F. Torres, and I. Corbella, "Extension of the clean technique to the microwave imaging of continuous thermal sources by means of aperture synthesis radiometers," *Progress In Electromagnetics Research*, PIER 18, 67–83, 1998.
8. Ding, L.-F. and F.-L. Geng, *Radar Principle*, Xidian University Press, Xi'an, 2002.

9. Cui, B., C. Wang, and X.-W. Sun, "Microstrip array double-antenna (MADA) technology applied in millimeter wave compact radar front-end," *Progress In Electromagnetics Research*, PIER 66, 125–136, 2006.
10. Wang, C. J., B. Y. Wen, Z. G. Ma, W. D. Yan, and X. J. Huang, "Measurement of river surface currents with UHF FMCW radar systems," *Journal of Electromagnetic Waves and Applications*, Vol. 21, No. 3, 375–386, 2007.
11. Alivizatos, E. G., M. N. Petsios, and N. K. Uzunoglu, "Towards a range-doppler UHF multistatic radar for the detection of non-cooperative targets with low RCS," *Journal of Electromagnetic Waves and Applications*, Vol. 19, No. 15, 2015–2031, 2005.
12. Fabbro, V., P. F. Combes, and N. Guillet, "Apparent radar cross section of a large target illuminated by a surface wave above the sea," *Progress In Electromagnetics Research*, PIER 66, 41–60, 2005.
13. Hough, P. V. C., "Method and means for recognizing complex patterns," U.S. Patent 3,069,654, Dec. 1962.
14. Carlson, B. D., E. D. Evans, and S. L. Wilson, "Search radar detection and track with the Hough transform: Detection performance with binary Integration," *IEEE Transactions on Aerospace and Electronic Systems*, Vol. 30, No. 1, 116–124, 1994.
15. Wood, J. C. and D. T. Barry, "Tomographic time-frequency analysis and its application toward time-varying filtering and adaptive kernel design for multicomponent linear-FM signals," *IEEE Trans. Signal Processing*, Vol. 42, No. 8, 2094–2104, 1994.