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A New Approach for LFMCW Radar using Wigner-Ville Distribution

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ABSTRACT

This paper introduces the application of Wigner- Ville Distribution (WVD) in LFMCW radar systems to perform the range-Doppler processing of targets instead of FFT processing. The proposed approach enhances the detection capability of the LFMCW radar based on the fact that the side lobe levels (SLLs) in WVD spectrum are very small in magnitude, this fact facilities the realization of LFMCW radar by WVD without the need of additional weighting to reduce SLL in FFT-based approach. Computer simulation via Monte Carlo trials is provided to evaluate the performance of the proposed WVD-based LFMCW radar compared to that of the FFT-based one. The Receiver Operating Characteristics (ROC) is used as the performance measure. Simulation results validate the superiority of the proposed approach.

KEY WORDS

LFMCW radar, WVD, and FFT.

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1-INTRODUCTION

LFMCW radars, as shown in figure (1), obtain target information by continuously transmitting linear frequency sweeps and mixing the delayed echoes from targets with a sample of the transmitted signal [1]. The target range information could be extracted from the spectrum of this mixed signal. Because of the wide-spectrum and the narrow beam width that is easily achieved, this kind of radar could work with high resolution and small size.

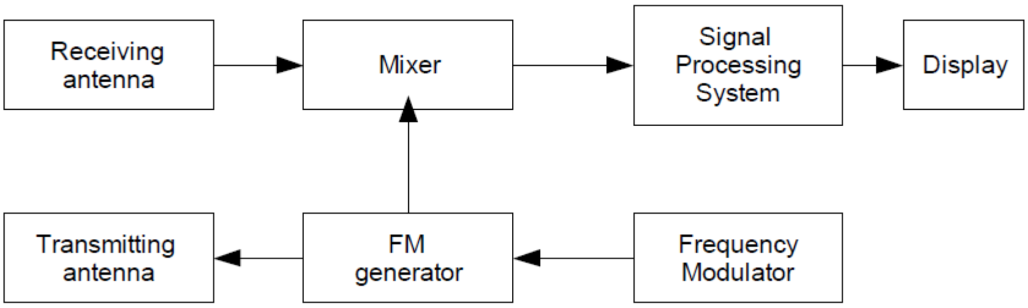


Fig.(1). Block diagram of LFMCW radar system [1].

Figure (2) shows the geometry of the frequency modulation and the obtained beat frequencies for fixed and moving targets.

The range information of a fixed target is obtained by the formula [2]:

$$R = \frac{f_b \, T_m \, C}{2 \, \Delta f} \qquad (1)$$

Where f_b is the beat frequency, T_m is the modulation interval, C is the speed of light, and Δf is the frequency excursion (the difference between the maximum and minimum frequency).

For moving target, the range information is given by the formula [2]:

$$R = \frac{CT_m}{4B}\left(\frac{f_b^{\,+} + f_b^{\,-}}{2}\right) \qquad (2)$$

Where B is the radar bandwidth, $f^{+}{}_{b}$ is the beat frequency shift due to positive slope, and $f^{-}{}_{b}$ is the beat frequency shift due to negative slope as shown in figure (2-c).

The velocity of the target is expressed as [2]:

$$v = \frac{\lambda}{2}\left(\frac{f_b^{\,+} - f_b^{\,-}}{2}\right) \qquad (3)$$

Where λ is the wavelength.

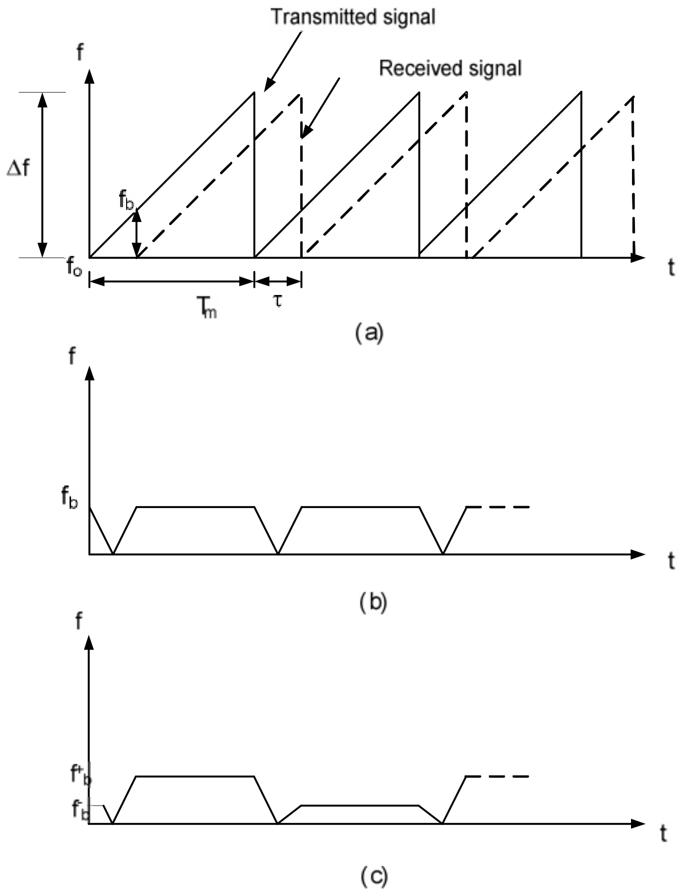


Fig.(2) The geometry of frequency modulation in LFMCW radar[2].
(a) Linear sawtooth frequency modulation of FMCW radar signal.
(b) Beat frequency between transmitted and received signals of fixed target.
(c) Beat frequency between transmitted and received signals of moving target.

The target movement causes a change in the phase of the received signal and the basic signal processing of LFMCW radar is to get value of the beat frequency. The common method of range-Doppler processing is to use two-dimensional FFT [3]. The first FFT is used to sample each frequency sweep to get a range profile, and the second one is used to sample the same range cell from consecutive frequency sweeps to extract Doppler information.

In the present work, the WVD is used instead of the FFT algorithm to perform the range-Doppler processing in LFMCW radar. The reason of using WVD is the fact that it presents very small SLL in the order of -32dB, facilitating the realization of LFMCW radar using WVD-based without resorting to additional weighting to reduce the sidelobes [4].

After the introduction, the rest of this paper is organized as follows: section 2 gives a survey on the principle of WVD. Section 3 describes the proposed approach for LFMCW radar with WVD. Computer simulations are provided in section 4. Finally, the conclusion comes in section 5.

2-PRINCIPLE OF WVD

The WVD is a potential useful tool for analyzing time varying signals, such as clutter, whose spectral characteristics vary with time; it has served as a useful analyzing tool in many fields as statistical physics, optics and image processing. In addition, it has been suggested as a modern method for analyzing many important topics including instantaneous frequency estimation, spectral analysis of non-stationary random signals, detections and classification, algorithms for computer implementation, and a wide range of applications such as radar, sonar [4].

The WVD of an analytical signal s(t) is defined as [5]:

$$WVD(t,f) = \int_T s(t+\frac{\tau}{2}) s^*(t-\frac{\tau}{2}) e^{-i2\pi f\tau} d\tau \qquad (4)$$

Where WVD (t,f) is the energy distribution of s(t) in time t and frequency f. WVD of a discrete sequence s(n) is defined as:

$$WVD(n,f) = \sum_{m=-\infty}^{\infty} s\{(n+m/2)\Delta t\} s^*\{(n-m/2)\Delta t\} \exp(-j2\pi fm\Delta t) \qquad (5)$$

The complex radar video signal is modified as [5]:

$$R(n,m) = s\{\lceil n+m/2 \rceil \Delta t\} s^*\{\lfloor n-m/2 \rfloor \Delta t\} + s\{\lfloor n+m/2 \rfloor \Delta t\} s^*\{\lceil n-m/2 \rceil \Delta t\} \qquad (6)$$

Where Δt is the sampling interval and n,m are integers. Ceiling function $\lceil x \rceil$ and floor function $\lfloor x \rfloor$ are defined as the smallest integer greater than or equal to x and the greatest integer less than or equal to x, respectively. The use of ceiling and floor functions avoids the difficulty of Eq.(6) owing to the unavailability of noninteger samples at mΔt/2. So, the WVD cited in Eq.(5) for the complex data becomes a simple DFT of Eq.(6) and is given by:

$$WVD(n,f) = \sum_{m=-\infty}^{\infty} R(n,m) \exp(-j2\pi fm\Delta t) \qquad (7)$$

In the next subsection, the application of WVD in LFMCW radar instead of FFT algorithm shall be discussed.

3-THE PROPOSED WVD-Based LFMCW RADAR

In the present work, application of WVD for range-Doppler processing in LFMCW radar instead of FFT algorithm is shown in figure (3). The complexity of WVD is higher than that of FFT [6]. But on the other side, FFT-based LFMCW radar uses a weighting algorithm after FFT to reduce SLL which is not necessary in the proposed WVD-based LFMCW radar. So, not using the weighting algorithm in the WVD-based LFMCW radar shall reduce the extra complexity of the proposed approach.

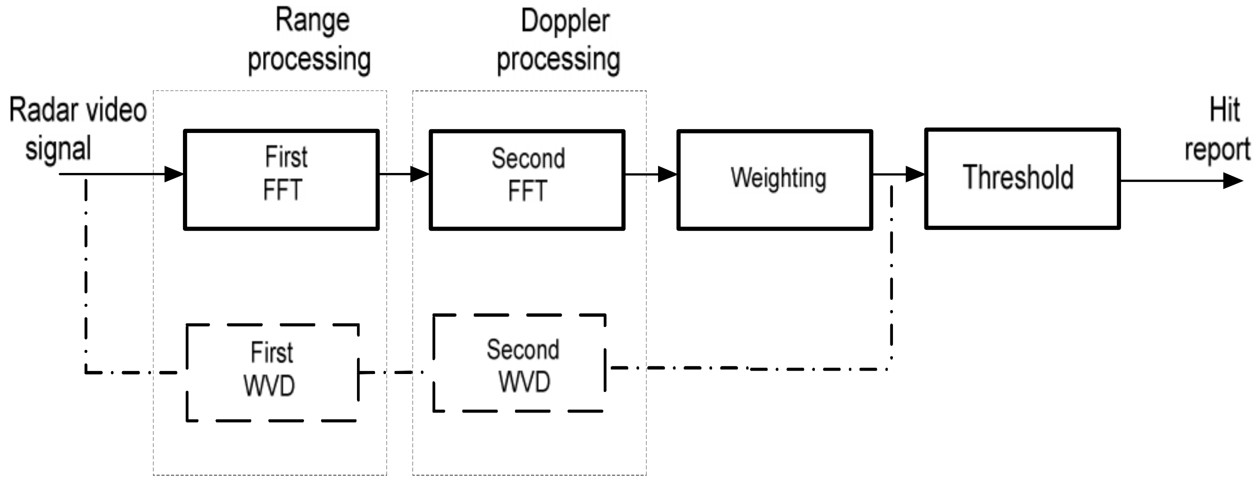


Fig.(3) Block diagram of signal processing in LFMCW radar.

The radar coverage area is divided into range-azimuth cells (N range cells and M azimuth cells) as illustrated in figure (4). The range processing is achieved by applying WVD for each raw. The result of the range processing array is processed for each column by second WVD to perform the Doppler processing.

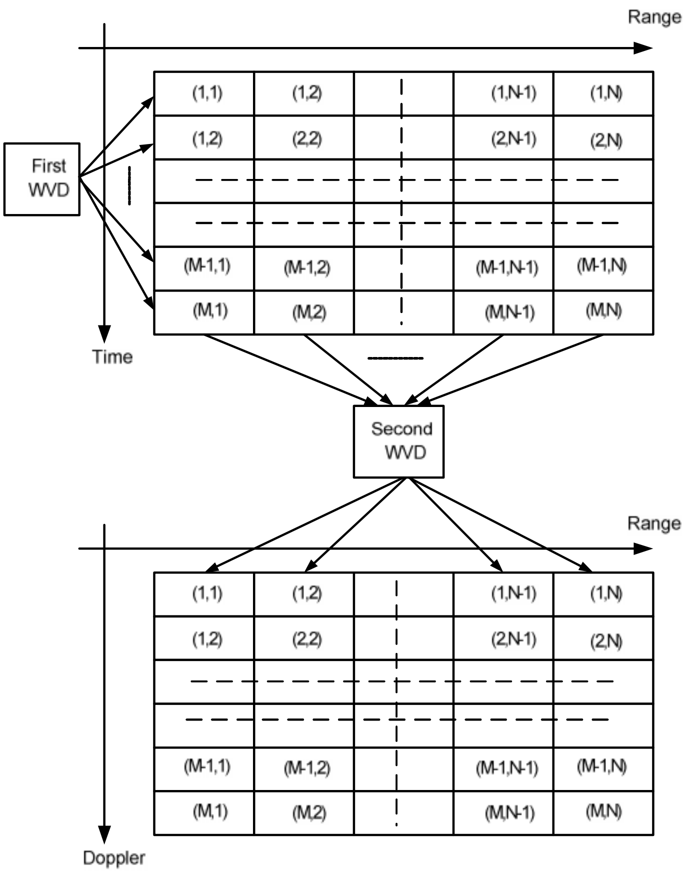


Fig.(4) Range-Doppler processing in WVD-based LFMCW radar [7].

In the next subsection, computer simulation is introduced to validate the superiority of the proposed approach.

4-COMPUTER SIMULATION AND RESULTS

The results are obtained by simulating both the FFT and the proposed WVD schemes using MATLAB 7.8. The simulation uses the Monte-Carlo method. A coherent processing interval (CPI) length of 128 cells in range and 16 cells in azimuth have been used for this work.

Figure (5) shows the relation between probabilities of false alarm for both FFT-based and WVD-based LFMCW radar at different threshold levels. The fact that WVD offers better sidelobe reduction has been the motivation factor for realizing the LFMCW radar using WVD. This is because of a sort of smoothing operation present in the kernel by virtue of its cross-multiplication operation in Eq.(6), which has the effect of reducing the SLLs. In addition, WVD-based LFMCW radar does not require an additional weighting operation, as is needed for FFT-based LFMCW radar [5].

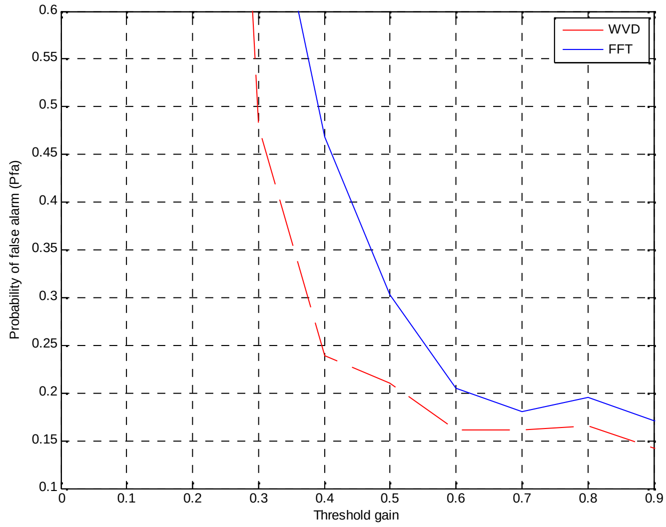
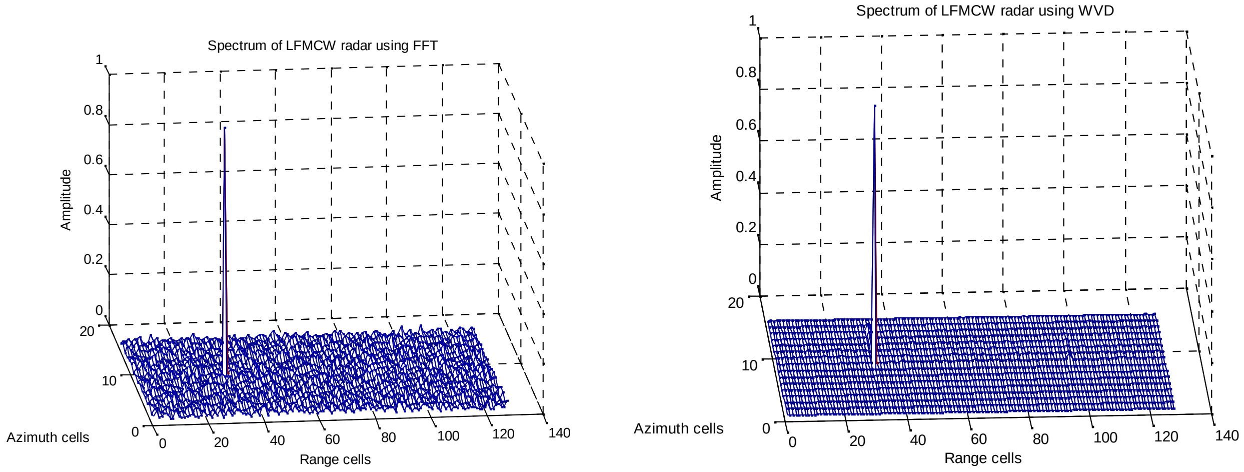


Fig.(5) The relation between probabilities of false alarm of LFMCW radar using FFT and WVD.

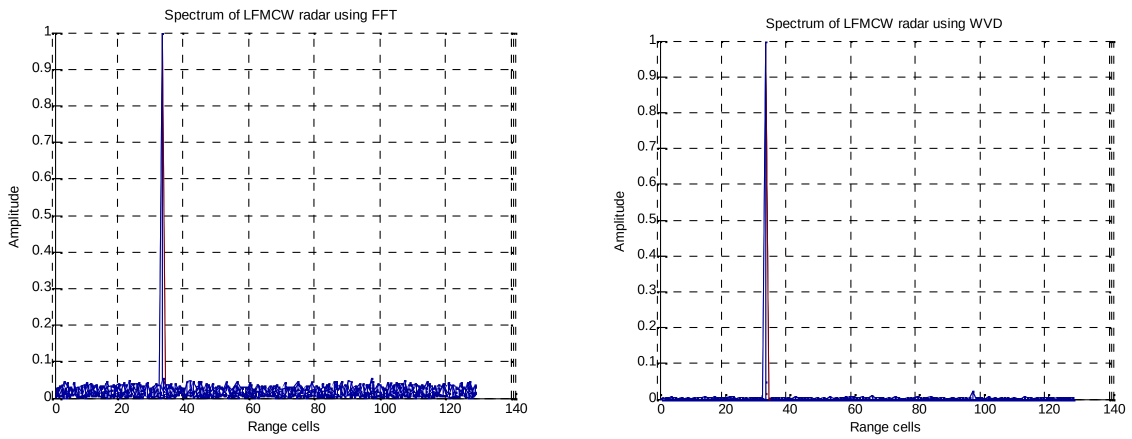
Figure (6) shows the result of range-Doppler processing using FFT-based and WVD-based LFMCW radar for single target at P_{fa} equals 10^{-4} and SNR is 10 dB.

Looking at the Doppler plane, figure (7) shows the reduction in SLL of WVD-based LFMCW radar compared to that of the FFT-based LFMCW radar.



(a) (b)

Fig.(6) Result of range-Doppler processing of LFMCW radar ($P_{fa}=10^{-4}$,SNR=10dB)
(a) FFT-based.
(b) WVD-based.



(a) (b)

Fig.(7) SLL of LFMCW radar (Doppler plane) ($P_{fa}=10^{-4}$,SNR=10dB)
(a) FFT-based.
(b) WVD-based.

Figures (8),(9), and (10) show the ROC curves for WVD-based and FFT-based LFMCW radar for $P_{fa}=10^{-4}$, 10^{-5} and 10^{-6} respectively. It is clear that the performance of the WVD-based LFMCW radar is better than that of FFT-based.

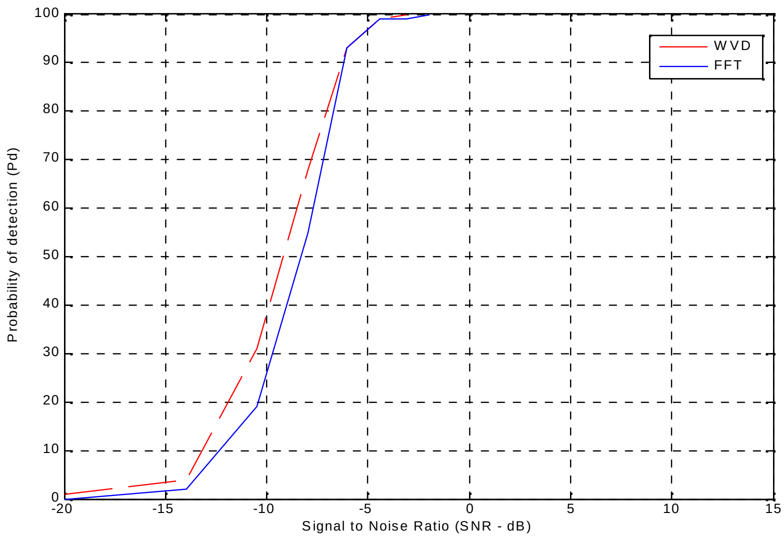


Fig.(8) ROC of the WVD-based LFMCW radar compared to the FFT-based LFMCW radar at $P_{fa}=10^{-4}$

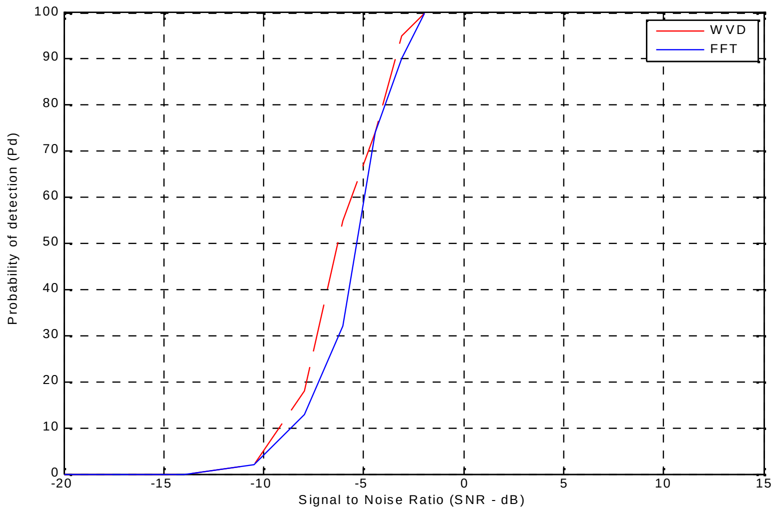


Fig.(9) ROC of the WVD-based LFMCW radar compared to the FFT-based LFMCW radar at $P_{fa}=10^{-5}$

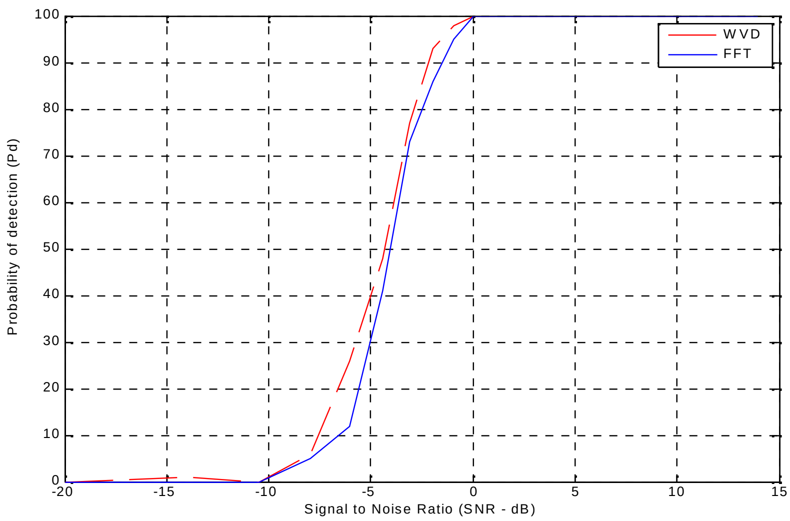


Fig.(10) ROC of the WVD-based LFMCW radar compared to the FFT-based LFMCW radar at $P_{fa}=10^{-6}$

In general, WVD-based LFMCW radar introduces a reduction in SLL compared to FFT-based LFMCW radar and consequently a lower probability of false alarm. Also it introduces an improvement in the detection capabilities. The WVD has cross-term problems in case of multi-targets due to bilinear nature. This problem could be eliminated but with increased complexity [8].

5-CONCLUSION

LFMCW radar has lots of advantages and had been broadly applied in many fields. In the presented work, a new approach for LFMCW radar using WVD instead of FFT is proposed. The proposed method enhances the detection performance capability of the LFMCW radar. This enhancement based on the fact that the WVD introduces less SLL than FFT. The extra calculation encountered in the WVD-based LFMCW radar is reduced by the elimination of the weighting algorithm in the FFT-based LFMCW radar. Computer simulation has been provided to validate the superiority of the proposed approach through the ROC curves.

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