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SHORT COMMUNICATION

Micro-Doppler Frequency Estimation Based on Radon-Wigner Transform

Sun Huixia* and Su Shidong
Yuncheng University, Yuncheng, Shanxi-044 000, China
**E-mail: huixiasun2004@163.com*

ABSTRACT

A nonparametric computationally efficient algorithm is proposed for micro-Doppler frequency estimation, assuming that this non-linear micro-Doppler frequency is approximate linear frequency in short-time intervals. In this algorithm, we use Radon-Wigner transform in short-time intervals to estimate micro-Doppler frequency. Simulation results confirm the effectiveness of the proposed method.

Keywords: Micro-doppler, frequency estimation, radon-wigner transform

1. INTRODUCTION

Mechanical vibration or rotation of a target, or structures on the target, may induce additional time varying frequency modulations on the returned radar signal, which generate sidebands about the target's Doppler frequency, called micro-Doppler effect[1-3]. Micro-Doppler can be regarded as a unique signature of the target and provides additional information that is complementary to the existing methods for classification and recognition. However, the existence of micro-Doppler could also contaminate the body image due to the interference from the vibrating or rotating parts of the target[4]. So the estimation of time-varying micro-Doppler frequency is of great importance. Micro-Doppler frequency estimation can be achieved by means of either nonparametric or parametric approaches. Among the nonparametric methods, two commonly used approaches are spectrogram peak measurement and the normalized first moment measurement, both of which are confined for monocomponent[5]. Parametric approach, such as extended Hough transform, however, suffers from the expensive computations and large storage requirements[6].

Aim of the study is to develop a nonparametric method for estimation of multicomponent micro-Doppler frequency. Authors formulated this problem as a dechirp problem by dividing the micro-Doppler frequency into several linear function since the signal segments in short time intervals are approximate linear FM (LFM)[7]. On one hand, this nonparametric method can be applied for multicomponent signals, on the other hand, the expensive computations and large storage requirements which parametric approach suffers from can be avoided.

2. PROBLEM FORMULATION

The point scattering model is usually used in simplifying the analysis while preserving the micro-Doppler features[1]. Without loss of generality, the geometry of the radar and a target with finite rotation point-scatterers is depicted in Fig. 1. R_0 is the distance between the rotation center O and the stationary radar, θ_0 is the angle between the radar line of sight (LOS) and the rotation plane. The target is composed of a finite number of rotating point-scatterers P_n. Assume that the scatterers P_n rotate about the rotation center O with a constant rotation rate ω_n and different rotation radii r_n and different initial phase φ_n.

The distance between the scattering center and radar can be denoted as follows

$$\begin{aligned} R_n(t) &= \sqrt{R_0^2 \sin^2\theta_0 + [R_0\cos\theta_0 - r_n\cos(\omega_n t+\varphi_n)]^2 + r_n^2\sin^2(\omega_n t+\varphi_n)} \\ &= \sqrt{R_0^2 - 2R_0 r_n\cos(\omega_n t+\varphi_n)\cos\theta_0 + r_n^2} \\ &\approx R_0 - r_n\cos(\omega_n t+\varphi_n)\cos\theta_0 \end{aligned} \tag{1}$$

If the radar transmits a sinusoidal waveform with a carrier frequency *f*, the baseband of the signal returned from the rotating point-scatterers is a function of $R_n(t)$

$$s(t) = \sum_n \sigma_n \exp\left\{ j2\pi f \frac{2R_n(t)}{c} \right\} = \sum_n \sigma_n \exp\left\{ j2\Phi_n(t) \right\} \tag{2}$$

where σ_n is the reflectivity function of the point-scatterer P_n, c is the speed of the electromagnetic wave propagation, the phase of the baseband signal is

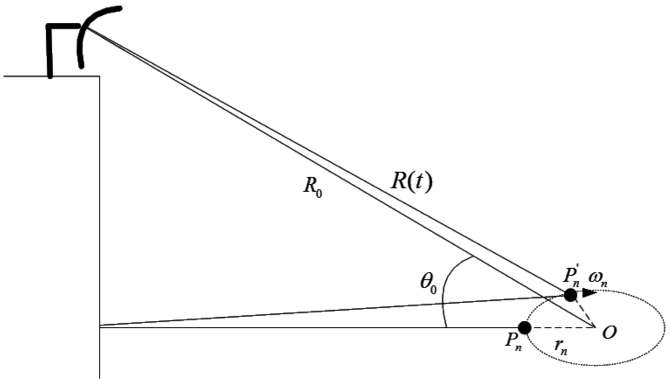

Figure 1. Geometry of radar and a target with finite point-scatterers.

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$$\Phi_n(t) = 2\pi f \frac{2R_n(t)}{c} \tag{3}$$

By taking the time derivative of the phase, the micro-Doppler frequency shift induced by the target's rotation is obtained

$$f_{mD} = \frac{1}{2\pi}\frac{d\Phi_n(t)}{dt} = \frac{2f}{c}\omega_n r_n \cos\theta_0 \sin(\omega_n t + \varphi_n) \tag{4}$$

which is a sinusoidal function of time oscillating at the rotation frequency.

3. MICRO-DOPPLER FREQUENCY ESTIMATION

From the analysis, the micro-Doppler frequency which is a sinusoidal function of time should be analyzed by time-frequency transforms. The problem is now reduced to that of estimating a constant frequency sinusoid. If the observation time is short enough, the time-varying frequency can be approximated as linear frequency modulated (LFM). Practically, we assume that the micro-Doppler frequency can be approximated by a piecewise linear function[5], for example, a sinusoid in a period can be approximated as two LFM with contrary chirp rate. The Wigner-Ville distribution has been found to provide ideal energy convergency capability on the time-frequency plane for mono-component LFM signal, however, it suffers from the problem of cross-term interference for multi-component signal. The Radon-Wigner transform (RWT) can eliminate interference of cross-term effectively and present good time-frequency concentration performance[8]. In this study, authors used RWT in short-time intervals to estimate micro-Doppler frequency.

Suppose the signal duration is *T*, and the sampling frequency is f_s. The proposed detection algorithm is as follows (without loss of generality, take two rotation parts for example):

(a) Extract the rotation periods by taking the autocorrelation of the time sequence data, which are denoted as T_1 and T_2, then the number of LFM in the returned radar signal can be calculated as $N_{l1} = \lfloor 2T/T_1 \rfloor$ and $N_{l2} = \lfloor 2T/T_2 \rfloor$, respectively. From which the points in each LFM are computed to be $N_1 = \lfloor T_1 f_s/2 \rfloor$ and $N_2 = \lfloor T_2 f_s/2 \rfloor$, where $\lfloor \cdot \rfloor$ denotes the round-off operation;

(b) Calculate the RWT of the returned radar signal among $\left[1, \max(N_1, N_2)\right]$ to estimate the first chirp rate u_1 and its initial frequency f_{d11}, then the second initial frequency f_{d12} can be evaluated by dechirping with slope $-u_1$ among $\left[\min(N_1, N_2), N_1 + N_2\right]$;

(c) The intersection point between the first LFM and the second LFM can be estimated by $a_{11} = \lfloor (f_{d12} - f_{d11}) f_s / 2u_1 \rfloor$, while the intersection point a_{12} between the second LFM and the third LFM can also be evaluated, from which the period of this rotation part can be obtained;

(d) After obtaining the parameters of the highest energy component, we can filter out this component by performing a dechirping transform and apply a rechirping transform to the residual component. Then repeat (b) and (c) to obtain the chirp rate u_2 and its initial frequency f_{d21} as well as the intersection point a_{21} of the second component;

(e) Estimate several frequencies in each LFM (in this paper, we take three frequencies), and use curve-fit method to obtain the instantaneous frequency curve.

4. SIMULATION RESULTS

Assume that the simulation parameters are as follows: $f = 3GHz$, $N = 512$, $f_s = 1000Hz$, $R_0 = 2000m$ and $\theta_0 = \pi/3\,rad$. The target is assumed to consist two rotation point-scatterers with $r_1 = 0.3m$, $\omega_1 = 12\pi\,rad/s$, $\varphi_1 = \pi/3\,rad$, and $r_2 = 0.4m$, $\omega_2 = 16\pi\,rad/s$, $\varphi_2 = 0\,rad$.

Figure 2(a) shows the theoretical result of the micro-Doppler frequency shift calculated from Eqn. (4). The extracted micro-Doppler signature by applying the algorithm developed in this paper is shown in Fig. 2(b), where the * represents the

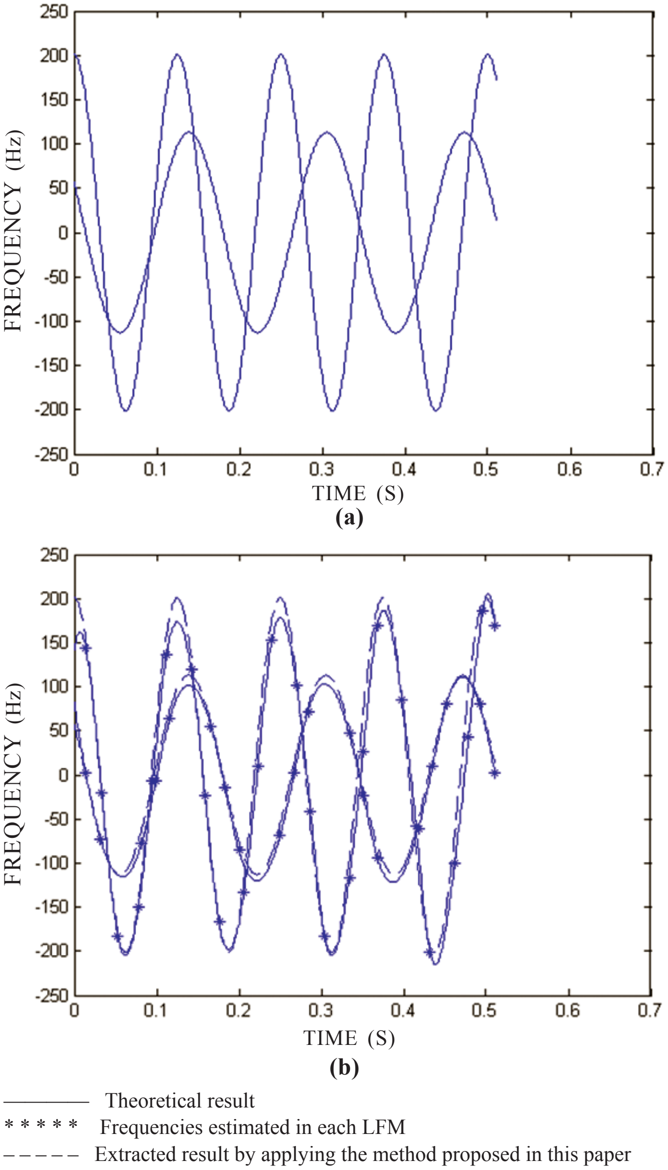

Figure 2. Micro-doppler frequency estimation (a) Theoretical result and (b) Extracted result.

frequencies estimated in each LFM, the fitting sinusoids can be seen as the dash-dot line, which is almost superposed with the theoretical result (shown in the solid line).

5. CONCLUSION

In this paper, we present a method for micro-Doppler frequency estimation by means of RWT based on the fact that micro-Doppler frequency can be approximated by a piecewise linear function. The proposed nonparametric method can be used for multicomponent signals while avoiding the expensive computations and large storage requirements of parametric approach.

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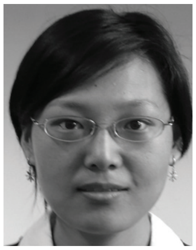
CONTRIBUTORS



Dr Sun Huixia obtained her BE and PhD in 2005 and 2011, respectively. Her research interests include radar signal processing and pattern recognition.

Mr Su Shidong obtained her BE in 1990. His research interests focus on electronics and computer applications.