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Aspects of Radar Imaging Using Frequency-Stepped Chirp Signals

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The high-resolution, frequency-stepped chirp signal can be applied to radar systems employing narrow-bandwidth chirp pulses, in order to enhance the range resolution, and to implement SAR/ISAR imaging capabilities. This paper analyzes the effect of moving targets on the synthetic high-resolution range profile obtained using this signal waveform. Some constraints are presented for compensation of the radial motion from shift and amplitude depression of the synthetic range profile. By transmitting two chirp pulses with the same carrier frequency in a pulse-set, a method of ground clutter cancellation is designed with respect to this signal format. Finally, our simulation data demonstrate the effectiveness of the proposed method.

1. INTRODUCTION

Radar range resolution is determined by the bandwidth of the transmitted pulse. Classically, high range resolution is obtained by either transmitting very short pulses, or modulating the pulse to achieve the required bandwidth. Frequency-stepping processing is another kind of a very effective method to obtain high downrange profiles of targets such as aircraft, and its applicability has been well documented [1]. The main advantage of this approach is that the actual instantaneous bandwidth of radar is quite small compared with the total processing bandwidth. This fact allows the transmission of waveforms with extremely wide overall bandwidth without the usage of the expensive hardware needed to support the wide instantaneous bandwidth. Thus, this technique can be utilized to introduce imaging capability to an existing narrow-bandwidth radar [2]. However, this method has the unfortunate drawback that target energy spills over into consecutive coarse range bins due to the matched-filter operation. This is the main reason why it is not regarded as a suitable method to process SAR images [3]. In addition, radar detection distance of the frequency-stepped signal is limited under the precondition of the definite range resolution. By means of synthetic bandwidth generated by frequency-stepped chirp signals instead of frequency-stepped narrow pulses, high range resolution can be realized and the detection distance can also be increased accordingly. Another advantage of replacing the fix-frequency pulse with chirp pulses is known to lower the grating lobes that appear in the range response [4, 15].

Using a synthesized chirp combining N pulses with an instantaneous bandwidth B_1, postprocessing is necessary to combine the individual chirps. Several methods are known as "frequency-jumped burst" [5, 17], or "synthetic bandwidth," [3, 6]. Concatenation of the individual chirps to one long chirp can be performed either in the time domain [3, 6, 8], or in the frequency domain [5], or in a deramp-mode [7].

For further suppression of grating lobes in frequency-stepped chirp train, several methods and some specific relationships on the signal parameters have been presented in [4, 6, 15]. Our simulation parameters in this paper follow the two specific relationships of [4].

We consider the effect of moving targets on the synthetic high-resolution range profile obtained using this signal waveform and present some constraints for compensation of the radial motion from the shift and the amplitude depression of the synthetic range profile. Meanwhile, a cancellation method of ground clutter based on this signal waveform is presented. We propose to retain the frequency-stepped chirps signal for high range resolution, but introduce a small variation to facilitate a simple first-order clutter cancellation procedure.

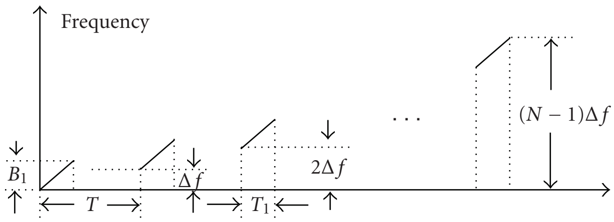

Figure 1: Sketch of frequency variety as a function of time, where T_1 is the duration time of the subpulse, T is the pulse-repetition time (PRT), and $f_0 + i\Delta f$ is the carrier frequency of the ith subpulse.

In Section 2, the frequency-stepped chirp signal and the principle of the synthetic high range resolution are briefly reviewed. Then, some aspects of the chirp frequency-stepped signal are discussed. In Section 3, some simulations are presented.

2. FREQUENCY-STEPPED CHIRP SIGNAL

The frequency-stepped chirp signal in the time domain is written as

$$\begin{aligned} u(t) &= \frac{1}{\sqrt{N}} \sum_{i=0}^{N-1} \widetilde{u}(t-iT) \exp\left(j2\pi i\Delta f t\right) \exp\left(j2\pi f_0 t\right) \\ &= \frac{1}{\sqrt{NT_1}} \sum_{i=0}^{N-1} \operatorname{rect}\left(\frac{t-iT}{T_1}\right) \exp\left[j\pi k(t-iT)^2\right] \\ &\quad \times \exp(j2\pi i\Delta f t) \exp\left(j2\pi f_0 t\right), \end{aligned} \tag{1}$$

where $\widetilde{u}(t) = (1/\sqrt{T_1})\operatorname{rect}(t/T_1)\exp(j\pi k t^2)$ is the chirp subpulse, k is the frequency slope, related to the bandwidth $B_1 > 0$ of the single chirp pulse according to

$$k = \pm\frac{B_1}{T_1}, \tag{2}$$

where a "$+$" sign stands for a positive frequency slope and a "$-$" sign stands for a negative frequency slope. We assume a positive frequency slope $k > 0$. T_1 is the duration time of the subpulse, T is the pulse-repetition time (PRT), $f_0 + i\Delta f$ is the carrier frequency of the ith subpulse, where $i = 0, 1, \ldots, N-1$, and N is the number of the subpulses (Figure 1), and Δf is the step size. Let the initial time of the signal be at $-T_1/2$, and the received echo from the target is

$$\begin{aligned} s_r(t) = \sum_{i=0}^{N-1} \operatorname{rect}\left[\frac{t-iT-\tau(t)}{T_1}\right] \exp\left\{j\pi k\left[t-iT-\tau(t)\right]^2\right\} \\ \times \exp\left\{j2\pi i\Delta f\left[t-\tau(t)\right]\right\} \exp\left\{j2\pi f_0\left[t-\tau(t)\right]\right\}, \end{aligned} \tag{3}$$

where $\tau(t) = 2R(t)/c$ is the delay time of the target, $R(t)$ is the distance between the target and the radar, and c is the wave propagation velocity. Mixing the echo with the reference signal, this yields [10]

$$\begin{aligned} s_r(t) = \sum_{i=0}^{N-1} \operatorname{rect}\left[\frac{t-iT-\tau(t)}{T_1}\right] \exp\left\{j\pi k\left[t-iT-\tau(t)\right]^2\right\} \\ \times \exp\left[-j2\pi i\Delta f \tau(t)\right] \exp\left[-j2\pi f_0 \tau(t)\right]. \end{aligned} \tag{4}$$

It can be seen that the echo of the frequency-stepped chirp signal can be divided into two parts as follows:

$$\begin{aligned} A_1 &= \operatorname{rect}\left[\frac{t-iT-\tau(t)}{T_1}\right] \cdot \exp\left\{j\pi k\left[t-iT-\tau(t)\right]^2\right\}, \\ A_2 &= \exp\left[-j2\pi i\Delta f\tau(t)\right] \cdot \exp\left[-j2\pi f_0\tau(t)\right], \end{aligned} \tag{5}$$

where A_1 is a chirp, and A_2 is the phase variation due to the stepped variety of the carrier frequency of the signal.

Thus, the signal processing is implemented by the following two steps: (1) the pulse compression of the chirp at each PRT gives the coarse range profiles; (2) the inverse discrete Fourier transform (IDFT) of the coarse range profile gives the refined range profile. Assuming that $\tau(t) = \tau = 2R/c$, that is, the target is fixed and the time delay is time-invariant, the output signal after the first pulse compression is

$$\begin{aligned} s_c(t) = \sum_{i=0}^{N-1} \sqrt{kT_1^2} \operatorname{rect}\left(\frac{t-iT-\tau}{T_1}\right) \frac{\sin\left[\pi k T_1 \cdot (t-iT-\tau)\right]}{\pi k T_1 \cdot (t-iT-\tau)} \\ \times \exp\left[-j\pi k(t-iT-\tau)^2\right] \exp\left(j\frac{\pi}{4}\right) \\ \times \exp(-j2\pi i\Delta f\tau) \exp\left(-j2\pi f_0\tau\right). \end{aligned} \tag{6}$$

Taking the sampling time at $t = iT + \tau$, $i = 0, \ldots, N-1$, the sampled digital signal is obtained as follows:

$$s_c(i) = \begin{cases} \sqrt{kT_1^2} \cdot \exp\left(j\dfrac{\pi}{4}\right) \exp(-j2\pi i\Delta f\tau) \exp\left(-j2\pi f_0\tau\right), & iT+\tau-\dfrac{T_1}{2} \le t \le iT+\tau+\dfrac{T_1}{2}, \\ 0 & \text{otherwise.} \end{cases} \tag{7}$$

Taking IDFT transform of $s_c(i)$ in terms of the discrete-time variable i, the high-resolution range profile is obtained as follows:

$$|S(l)| = \sqrt{kT_1^2}\left|\frac{\sin\pi(l - N\Delta f\tau)}{N\sin\pi(l/N - \Delta f\tau)}\right|. \tag{8}$$

2.1. Effect of velocity on range profile

As shown in (4), the echo of the frequency-stepped chirp signal can be divided into two parts. Therefore, the Doppler effect on the frequency-stepped chirp signal consists of two parts: (1) the effect on the chirp subpulse compression, and (2) the second compression within the frequency-stepped burst. The effect on the frequency-stepped pulse compression causes the phase errors [10], where the linear phase error and the square phase error are, respectively, due to the movement of the synthetic range profile in the position and the energy diversion of the synthetic range profile. The phase error can be compensated in the digital signal sequence. With respect to the linear phase error, the precision of compensation should satisfy the constraint of [10]

$$|\Delta V| < \frac{c}{4Nf_0T}. \tag{9}$$

The compensation criterion for the square phase error, which might distort the synthetic range profile, is as follows:

$$|\Delta V| < \frac{c}{8N^2\Delta fT}. \tag{10}$$

Now we discuss the effect on the chirp subpulse compression. Assuming that the target moves with a relative velocity V towards the radar, the time delay is

$$\tau(t) = \frac{2R - Vt}{c}. \tag{11}$$

Sampling is carried out for each PRT at the time $iT + 2R/c + t'$, where $t' \in (-T_1/2, T_1/2)$, and it yields

$$\tau(t) = \frac{2R}{c} - \frac{2V}{c}iT - \frac{2V}{c}\frac{2R}{c} - \frac{2V}{c}t'. \tag{12}$$

Taking the pulse compression, the coarse range profile is compressed as

$$\begin{aligned}&\operatorname{rect}\left[\frac{t - iT - 2R/c + (2V/c)iT}{T_1}\right]\\&\quad\times\sqrt{kT_1^2}\frac{\sin\pi(f_{di} + kt')T_1}{\pi(f_{di} + kt')T_1}e^{-j\pi kt'^2}e^{j\pi/4},\end{aligned} \tag{13}$$

where $f_{di} = (2V/c)(f_0 + i\Delta f)$ is the Doppler frequency.

After the first pulse compression, a sinc function in (13) is produced. Because the signal processing is generally done in the main lobe of the sinc function with the main lobe width $B_1 = kT_1$, the small phase error caused by the nonlinear variable $\pi kt'^2$ is actually negligible. This can be seen from the maximum of the variable phase as $\pi/(4kT_1^2)$ for $t' \in (-1/2kT_1, 1/2kT_1)$ and $kT_1 \gg 1$.

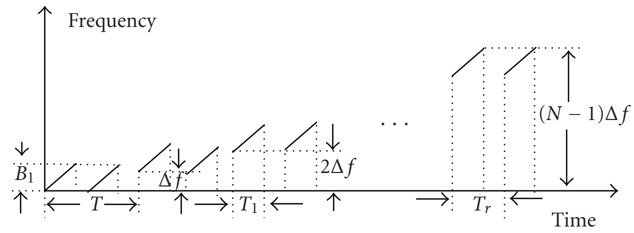

Figure 2: Sketch of frequency variety of the pulse-set which consisted of two chirp pulses at the same carrier frequency, where T_r is the pulse-repetition time inside the pulse-set.

Due to the Doppler effect of the moving target, the peak of the synthetic range profile is actually not at the target's real position. This coupling time variation is written as $\Delta\tau = f_{di}/k = [(f_0 + i\Delta f)/k](2V/c)$ for each PRT. Note that $2f_0V/kc$ is PRT-invariant and $2i\Delta fV/kc$ is a variable. Due to $f_0/k \ll 1$ and $2V/c \ll 1$, this variable is also very small and negligible.

As the target is moving, the peak of the output waveform after the chirp pulse compression, that is, the coarse synthetic range profile, moves among the different PRTs. It can be seen from the envelope of (13) that the waveform maximum moves $2VT$ between the two PRTs. Thus, the total maximum variation in the range domain would not exceed $2VNT$ for N chirp pulses, and the total maximum variation in the time domain is $2NVT/c$. It has been known that in imaging process, the criterion of the range profile migration is usually less than 1/2 range cell, that is, $1/(2B_1)$ [13, 14]. Thus, the constraint condition without range shift is

$$\frac{2V}{c}NT < \frac{1}{2B_1} = \frac{1}{2kT_1}. \tag{14}$$

Note that the above discussion is based on ISAR imaging. In ISAR imaging for a moving target, the target size is much smaller than the terrain scale of SAR imaging. Thus, we can sample only one point within the sinc main lobe shown in (13) and implement the second pulse compression. Moreover, it is not necessary to consider the waveform combining problem, which will arise in SAR imaging for a large area.

2.2. A method for ground clutter cancellation

A method of the ground clutter cancellation with respect to the frequency-stepped signal can be found in [9], and the clutter cancellation of the chirp signal using the match filtering and stretching process can be found in [11, 12], respectively. Now we discuss the cancellation method of the frequency-stepped chirp signal based on the stretch processing.

Making use of the delay-line technique [16] to eliminate the ground clutter, a signal similar to the format of [9] is designed. As shown in Figure 2, a series of bursts is transmitted, where each burst is a sequence consisting of N pulse-sets stepped in frequency from pulse-set to pulse-set by a fixed step Δf. Each pulse-set consists of two chirp pulses at the same carrier frequency, that is, without a frequency step.

As a single point target is moving with a uniform velocity, the first chirp signal of the ith pulse-set is

$$\begin{aligned} u_i(t) &= \exp\{j[2\pi(f_0 + i\Delta f)t]\} \\ &\quad \cdot \exp(j\pi k t^2), \quad iT \le t \le iT + T_1. \end{aligned} \tag{15}$$

Assuming that the fast time delay of the radar from the target and the reference point are τ_p and τ_c, respectively, the echo and the reference signals can be expressed as follows:

$$\begin{aligned} s_i(t) &= u_i(t-\tau_p), \\ s_{ic}(t) &= u_i(t-\tau_c). \end{aligned} \tag{16}$$

After the stretching process, we obtain [12, 16]

$$\begin{aligned} s_{1,i}(t) &= s_i(t) \cdot s_{ic}^*(t) \\ &= \exp(j2\pi\Delta F_i t)\exp(j\varphi_i), \end{aligned} \tag{17}$$

where $\Delta F_i = -k(\tau_p - \tau_c) = -k \cdot \Delta\tau_p$, $\varphi_i = -2\pi[(f_0 + i\Delta f)\Delta\tau_p - (k/2)\Delta\tau_p^2]$. Then, the first pulse compression can be implemented via the Fourier transform of (17).

The discretized format of (17) is written as

$$s_{1,i}(n) = \exp(j2\pi\Delta F_i n\Delta t)\exp(j\varphi_i), \tag{18}$$

where Δt is the sampling time interval, $n = 0, 1, \dots, N_1 - 1$, $N_1\Delta t = T_1$.

Denoting the moving point target as a and the fixed point target as b, the radial velocity of the moving target to the radar as v, and the pulse repetition interval of two chirps within a same pulse-set as T_r, the fast-time delay of the echoes from a and b take $\tau_a(i) = 2R_a(i)/c$ and $\tau_b(i) = 2R_b(i)/c$, where R_a and R_b denote the distance of radar to the point targets a and b, respectively. Mixing with the $i = 2l$th echo signal, the reference signal must be the same as the last one to mix with the $i = (2l-1)$th echo signal, that is, $\tau_c(2l-1) = \tau_c(2l)$. In other words, *the two echoes within a same pulse-set are mixed with a same reference signal.* It is important to keep the correlation between these two echoes. As shown in Figure 2, each pulse-set consists of two chirp pulses at the same carrier frequency. Thus, the carrier frequency of $i = 2l$th echo is the same as that of the $i = (2l-1)$th echo, that is, $f_0 + (2l-1)\Delta f$. Assuming that $\Delta\tau_a(i) = \tau_a(i) - \tau_c(i)$ and $\Delta\tau_b(i) = \tau_b(i) - \tau_c(i)$, the two echoes can be written as follows:

$$\begin{aligned} &s_{1,2l-1}(n) \\ &\quad = \exp(-2\pi jk \cdot \Delta\tau_a(2l-1)n\Delta t) \\ &\qquad \cdot \exp\left(-2\pi j\left((f_0+(2l-1)\Delta f) - \left(\frac{k}{2}\right)\Delta\tau_a(2l-1)^2\right)\right) \\ &\qquad + \exp(-2\pi jk \cdot \Delta\tau_b(2l-1)n\Delta t) \\ &\qquad \cdot \exp\left(-2\pi j\left((f_0+(2l-1)\Delta f) - \left(\frac{k}{2}\right)\Delta\tau_b(2l-1)^2\right)\right), \end{aligned} \tag{19a}$$

$$\begin{aligned} &s_{1,2l}(n) \\ &\quad = \exp(-2\pi jk \cdot \Delta\tau_a(2l)n\Delta t) \\ &\qquad \cdot \exp\left(-2\pi j\left((f_0+(2l-1)\Delta f) - \left(\frac{k}{2}\right)\Delta\tau_a(2l^2)\right)\right) \\ &\qquad + \exp(-2\pi jk \cdot \Delta\tau_b(2l)n\Delta t) \\ &\qquad \cdot \exp\left(-2\pi j\left((f_0+(2l-1)\Delta f) - \left(\frac{k}{2}\right)\Delta\tau_b(2l)^2\right)\right). \end{aligned} \tag{19b}$$

Since the point target b is fixed, that is, $\tau_b(2l-1) = \tau_b(2l) = \tau_b$, the second terms of (19a) and (19b) are the same. After first-order cancellation, this yields

$$\begin{aligned} &s_{1,2l}(n) - s_{1,2l-1}(n) \\ &\quad = \exp(-2\pi jk \cdot \Delta\tau_a(2l)n\Delta t) \\ &\qquad \cdot \exp\left(-2\pi j\left((f_0 + (2l-1)\Delta f) - \left(\frac{k}{2}\right)\Delta\tau_a(2l)^2\right)\right) \\ &\qquad - \exp(-2\pi jk \cdot \Delta\tau_a(2l-1)n\Delta t) \\ &\qquad \cdot \exp\left(-2\pi j\left((f_0+(2l-1)\Delta f) - \left(\frac{k}{2}\right)\Delta\tau_a(2l-1)^2\right)\right). \end{aligned} \tag{20}$$

It can be seen that the fixed-point scatterer which represents the ground clutter has been removed. The residual term is the difference between the two echoes from the moving target, and its envelope takes the following form [16]:

$$2\sin(-\pi k f_d \cdot T_r n\Delta t + \phi_0)\cos(\tilde{\omega} \cdot n\Delta t + \phi_1), \tag{21}$$

where $f_d = 2v/c$, T_r is the pulse-repetition interval of the two chirps, and

$$\begin{aligned} \Delta\tau_a(2l) - \Delta\tau_a(2l-1) &= \frac{2(R_a(2l) - R_a(2l-1))}{c} \\ &= \frac{2v \cdot T_r}{c} = f_d \cdot T_r, \\ \phi_0 &= \pi\left(\left(\frac{k}{2}\right)\Delta_a(2l)^2 - \left(\frac{k}{2}\right)\Delta_a(2l-1)^2\right), \\ \tilde{\omega} &= -\pi k(\Delta_a(2l) + \Delta_a(2l-1)), \\ \phi_1 &= -\pi\left(2f_0 + (4l-2)\Delta f - \left(\frac{k}{2}\right)\Delta_a(2l)^2 - \left(\frac{k}{2}\right)\Delta_a(2l-1)^2\right). \end{aligned} \tag{22}$$

Table 1: Parameters of radar.

Carrier frequency	f_0	10 GHz
Frequency step size	Δf	12.5 MHz
Number of steps	N	24
Chirp bandwidth	B_1	31.25 MHz
Pulse length	T_1	400 ns
Chirp rate	k	7.8125×10^{13} Hz/s
Coarse range resolution	ΔR_c	4.8 m
Refined range resolution	ΔR_s	0.5 m
Pulse-repetition frequency	PRF	20 KHz

Its amplitude is written as

$$\left| 2 \sin \left(\pi k f_d \cdot T_r n \Delta t + \phi_0 \right) \right|. \tag{23}$$

Then, the refined range profile can be achieved via the second pulse compression.

3. SIMULATIONS

It has been shown in [4] that a suitable choice of parameters allows one to nullify several (or, sometimes, even all) grating lobes. Thus, we select these parameters according to a relation on two signal parameters ($T_1 B = 12.5$ and $T_1 \Delta f = 5$. Note that k and B_1 in (2) are not the ultimate values of the single pulse slope and bandwidth. The ultimate bandwidth of each pulse is $B = |k + k_s| t_p$ [4], where $k_s = \pm \Delta f / T$, $\Delta f > 0$, where a "⊣" sign stands for a positive frequency step and a "−" sign stands for a negative frequency step. Hence we will assume a positive frequency step $k_s > 0$, but the results apply to a negative step as well). Table 1 shows some of the radar parameters that are used to create the wide-bandwidth signal.

3.1. Simulation of synthetic range profile

In simulation, we suppose that a target is composed of three scatterers locating on the line of sight (LOS) of radar. The distance between radar and target is 10 km. The distances between one main scatterer and two other scatterers are 2 m and 2.6 m, respectively. Figure 3 shows a coarse range profile obtained via the chirp pulse compression. It can be seen that three scatterers cannot be distinguished from the coarse range profiles with a range resolution $\Delta R_c = c/2B_1 = 4.8$ m.

After the second pulse compression by using the frequency-stepped technique, the refined range resolution is obtained and three point targets can be clearly distinguished, as shown in Figure 4. Figure 5 shows the difference of the synthetic range profiles with different velocity errors. Because the velocity errors are not compensated completely at the velocity error 3 m/s, these point targets cannot be distinguished due to the energy diversion.

3.2. Simulation of ground clutter cancellation

First, suppose that there is a uniformly distributed random ground clutter in the imaging background. The signal-to-clutter ratio is −25 dB. Figure 6 depicts the simulated target

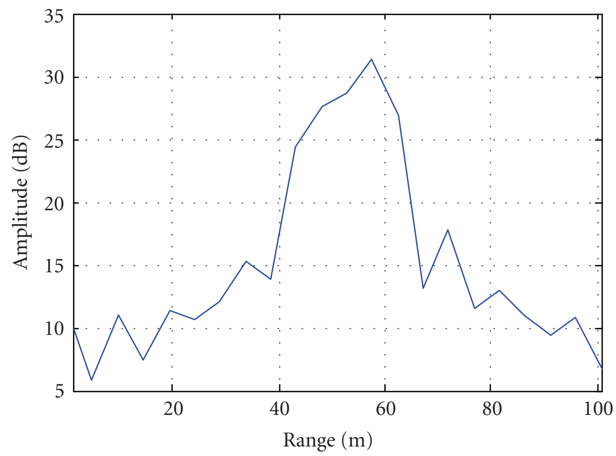

Figure 3: Synthetic coarse range profile using chirp-pulse compression, where coarse range resolution is 4.8 m.

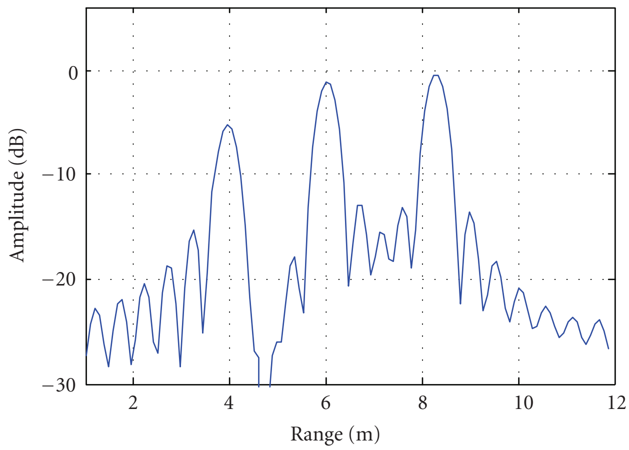

Figure 4: Synthetic refined range profile after the second pulse compression, where range resolution is 0.5 m.

mode, which consists of 63 scatterers. The target size is 10 m and 4 m in length and width, respectively. As shown in Figure 2, each pulse-set consists of two chirp pulses at the same carrier frequency and the pulse-repetition interval $T_r = 25$ microseconds. The distance between the radar and the target center is 10 km. The moving direction of the target is assumed to be parallel to the moving direction of the radar. The relative velocity between the radar and the target is $V = V_r - V_t = 380$ m/s, where V_r and V_t are the velocity of radar and target, respectively. The imaging time is about 0.8 second and the cross-range resolution is 0.5 m.

Figure 7 is the target image with no clutter. In imaging processing, the side lobe of the synthetic range profiles is suppressed using the Hamming window after removing the residual video phase (RVP) errors.

When the clutter is introduced, the ISAR imaging without clutter cancellation is shown in Figure 8. The target cannot be identified at all. Figure 9 shows the imaged result of our proposed clutter cancellation. It can be seen that after the

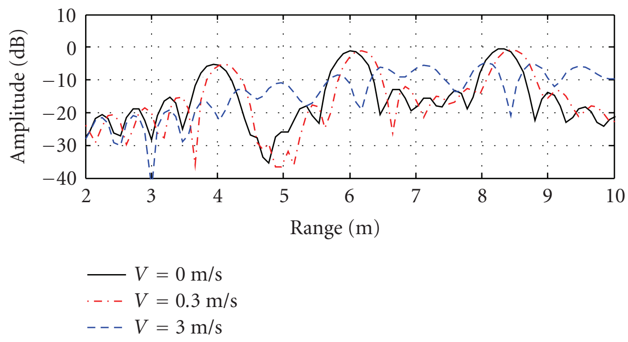

FIGURE 5: Comparison of synthetic range profiles with the different velocity errors, where the velocity error = 0, 0.3, 3 m/s, respectively.

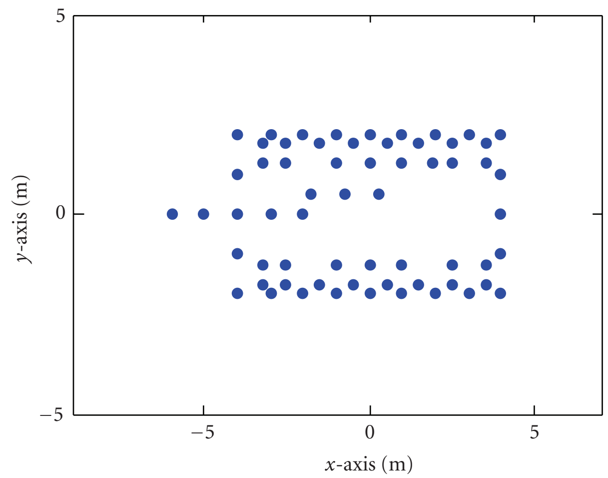

FIGURE 6: Target mode.

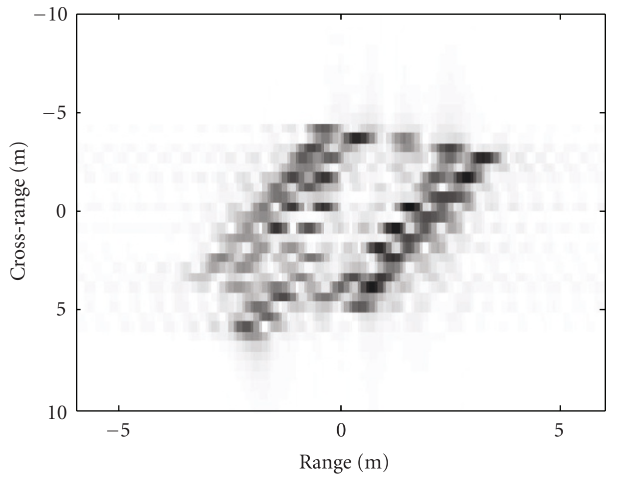

FIGURE 7: Radar image of the simulated tank without the ground clutter.

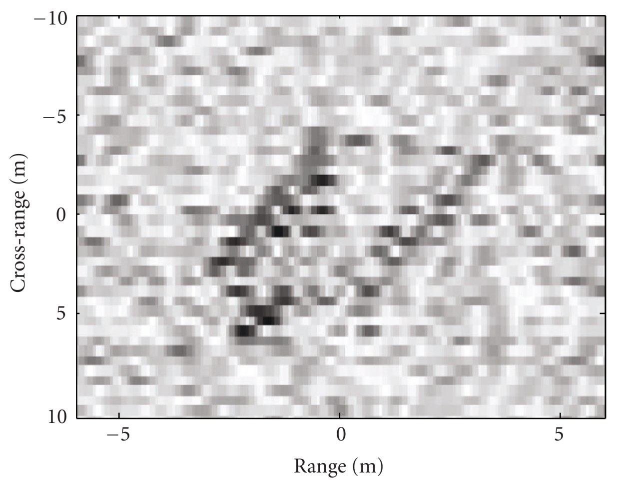

FIGURE 8: Radar image when the clutter is not eliminated.

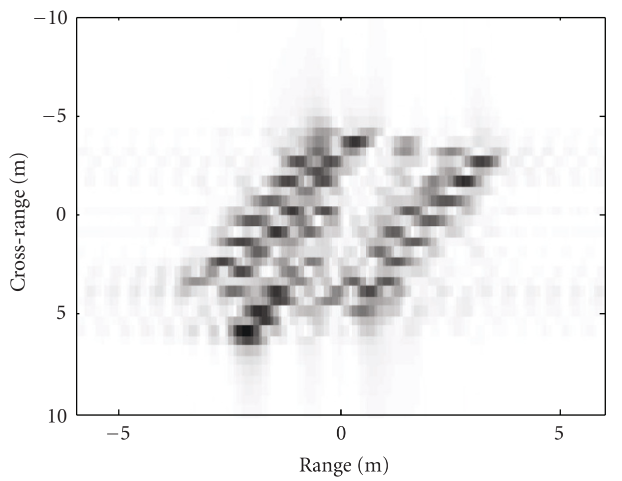

FIGURE 9: Radar image of the simulated target using the proposed clutter cancellation method.

ground clutter is eliminated, the target image is well identified.

Next we investigate the imaging results when the ground clutter scatterers are not fixed anymore, that is, the clutter movement (due to wind, etc.) is in existence. Assume that the positions of the ground clutter scatterers shift during imaging processing with different velocities and in different directions. Between the two received echoes, both the shift velocity and the shift direction of each ground clutter scatterer change randomly within some fixed extents. When the variation of these random velocities is $(-1\text{ m}, 1\text{ m})$ and $(-5\text{ m}, 5\text{ m})$, the resultant imaging results are shown in Figures 10 and 11, respectively. It can be seen that the first one in Figure 10 is still acceptable although the image has been somewhat degraded, but, in Figure 11, the target can hardly be distinguished from the resultant image anymore.

As mentioned in [9], the second-order (or even higher-order) cancellation can be used to eliminate the clutter by transmitting three or more chirp pulses of the same carrier frequency in each pulse-set. Intuitively, these higher-order cancellations are expected to produce better cancellation under the worst signal-to-clutter ratio according to

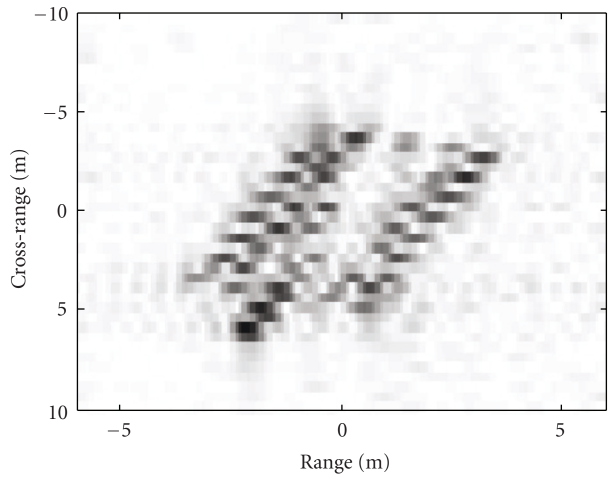

Figure 10: Imaging result using the proposed clutter cancellation method, where the clutter scatterers are randomly moving in the imaging process within (−1 m, 1 m).

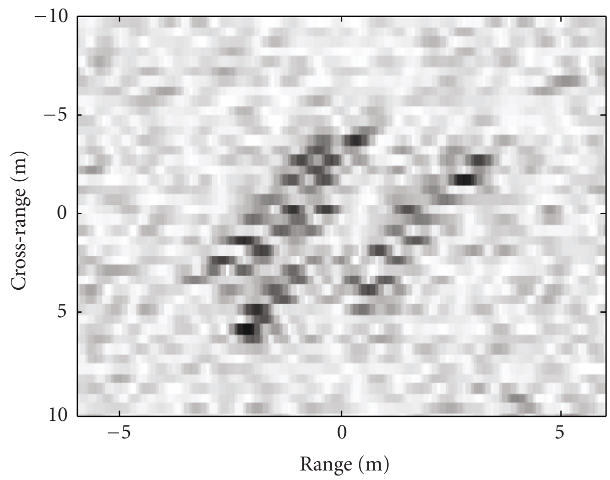

Figure 11: Imaging result using the proposed clutter cancellation method, where the clutter scatterers are randomly moving in the imaging process within (−5 m, 5 m).

the principle of the delay-line technique [16]. However, it must be considered carefully together with the other issues of the frequency-stepped chirp, for example, the range profiles splitting, motion compensation, and so forth.

4. CONCLUSIONS

Using the frequency-stepped chirp signal, the signal bandwidth can be greatly enhanced, and as a result, the high range resolution can be achieved. In this paper, the influences of the velocity on the synthetic range profiles are analyzed and some constraint conditions of the velocity compensation are presented, not only for the frequency-stepping processing, but also for the chirp subpulse compression. These constraints are useful for designing the imaging radar system with SAR technique or ISAR technique. Based on the delay-line technique, the method of new signal format to eliminate the ground clutter is presented.

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