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A high-speed target detection algorithm based on frequency compensation

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ABSTRACT

The speed of modern vehicles becomes higher and higher along with the development in supersonic technology and this brings challenge to detection by conventional radars. This article studies the problems encountered in high-speed target detection by conventional radars. Firstly, it analyzes the factors affecting the range migration of high-speed target echo envelope and gives three algorithm structures for high-speed target range migration. Secondly, this article reviews the characteristics of the three algorithm structures and, based on coordinate transformation, proposes a high-speed target detection algorithm using frequency compensation structure; this algorithm is capable of accomplishing first-order and second-order term compensation of high-speed target range migration. Finally, the validity and advantage of this algorithm are verified by experiment data.

1. Introduction

In recent years, high-speed target detection has attracted more and more attention in radar signal detection field. For instance, MIT Lincoln Laboratory, Lockheed Martin Technology Research Center, Laval University (Canada), University of Rome (Italy) have carried out a great deal of research on this subject. Long-time coherent accumulation technique is found to be an effective way for detecting high-speed weak targets; however, the target echo envelope moves between different pulse repetition periods due to long-time accumulation, traditional target-based moving target detection techniques are no longer effective in detecting such targets, and it is necessary to perform echo envelope alignment before detection. Regarding range migration compensation techniques of envelope alignment, Ref. [1] proposes an envelope correlation technique for envelope alignment. This technique applies magnitude correlation to envelope alignment by using adjacent echoes as the basis, but practically the drift caused by error accumulation and the jump caused by flickering are unavoidable. Ref. [2] suggests using the correlation among multiple pulse envelopes to achieve envelope alignment, which may remove stochastic error caused by adjacent envelope correlation technique; however, with a low SNR this technique is not effective in extracting envelope correlation characteristics and is unable to complete envelop alignment among multiple pulses. Taking advantage of the quasi-linearity between target echo envelope movement and accumulated time, Refs. [3,4] suggest a technique called WVD, which uses WVD to complete signal detection in time-frequency domain. However, this technique is troubled by heavy computation as well as poor detection performance when SNR is low. This technique has such downsides as heavy

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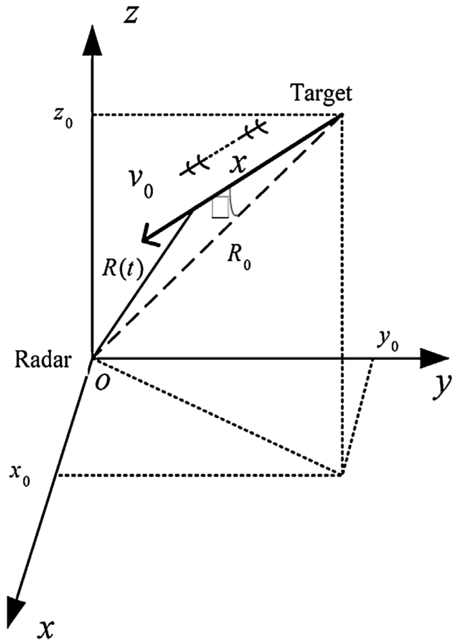

Fig. 1. Sketch of Target-Radar Location.

computation as well as poor detection performance when SNR is low. Refs. [5–7] propose using Keystone to remove linear displacement term in target echoes and to further remove terms of higher orders so as to detect the target. However, this technique needs frequency domain interpolation, involving complicated and heavy computation. One may resort to a quick computation, but it is necessary to overcome speed blurring. Refs. [8–10] apply maximum likelihood criterion to envelope alignment. Refs. [11] suggests using Hough transform (HT) technique to estimate high-speed targets, however it does not give actual computation process of HT technique.

The aforementioned techniques primarily deal with first-order term migration compensation of high-speed targets; however, they are found to be computation intensive in engineering application. Consequently, taking common radars (chirp pulse compression radar) as an example, this article analyzes the causes of range migration and studies three structures of range migration compensation algorithm. Relying on time-frequency transformation, this article proposes a range migration technique based on frequency compensation. This technique is able to complete first-order and second-order term compensation of range migration, capable of detecting high-speed targets, and is found superior to other techniques in computation efficiency and echo energy accumulation.

2. Impact of high-speed targets on radar echoes

2.1. Factors affecting radar echoes

The actual form of radar echoes is dependent on such factors as target movement state and radar location; for convenience of analysis, a general model is studied in this article, assuming the high-speed target and the radar has a geometry as shown in Fig. 1 below.

In Fig. 1, the radar is located at the origin whilst the target is at x_0, y_0, z_0. The target, whose initial velocity is v_0, is flying toward the radar. R_0 is the initial range between the target and the radar, ${R_0}^2 = {x_0}^2 + {y_0}^2 + {z_0}^2$. α is the movement direction angle of the target with respect to the sight line of the radar. From cosine theorem, the instantaneous range of the target relative to the radar may be expressed by:

$$\begin{aligned} R(t) &= \sqrt{R_0^2 + x^2 - 2R_0 x \cos\alpha} \\ &= \sqrt{R_0^2 + {v_0}^2 t^2 - 2R_0 v_0 t \cos\alpha} \end{aligned} \tag{1}$$

After Taylor series expansion of Eq. (1) and omitting terms of 4 and higher orders, we get:

$$R(t) \approx R_0 + \frac{dR(t)}{dt}|_{t=0} \times t + \frac{1}{2!}\frac{d^2R(t)}{dt^2}|_{t=0} \times t^2 + \frac{1}{3!}\frac{d^3R(t)}{dt^3}|_{t=0} \times t^3 \tag{2}$$