Compensation arithmetic of envelope based on Keystone Transform

Ding Qiuqi, Jiang Zhiyu, Li Qifu and Fu Gang

China Satellite Maritime Tracking and Control Department, Jiangyin, 214431, China

Keywords: Keystone; envelope; compensation algorithm

Abstract. Envelope interpolation motion compensation algorithm is considered from the time domain, interpolation of the envelope and shift processing. This article first elaborated the principle of Keystone transform, and then analyzed for the presence of the Keystone transform envelope moving the issue of compensation and gives the algorithm implementation. Simulation results further demonstrate the effectiveness of the algorithm.

Introduction

According to the theory of the radar signal, or when the target is far from the target RCS is small, the echo signal is very weak, or even lower at 0dB SNR usually less difficult to meet the testing requirements, which requires a plurality of pulse echo accumulate. For LEO satellites or space debris as high-speed moving target, since the change of the target distance during the observation time large, the echoes envelope serious phenomenon walking distance, if not effectively compensate the echo envelope spread over a lot of distance unit, thus greatly reducing the accumulated gain. Therefore, to achieve a long coherent integration, you must first find a suitable envelope walking Compensation.

The basic principle of Keystone Transform

This article describes the Keystone transformation principle, required from the perspective of the frequency signal model derivation. In this paper, some theoretical basis for Chirp signal matched filter processing, the matched filter in the frequency domain is expressed as:

$$S_o(f, i) = \frac{1}{k} \text{rect} \left[\frac{f - f_d/2}{B - |f_d|} \right] \cdot \exp \left(-j \frac{\pi}{k} f_d^2 \right) \cdot \exp \left[-j 2 \pi f (\tau_i - f_d/k) \right] \cdot \exp \left[-j 2 \pi (f_0 - f_d) \tau_i \right] \quad (1)$$

Analysis of equation (1) second phase term:

$$\begin{aligned} \varphi_{o2} &= -2 \pi f (\tau_i - f_d/k) \\ &= -2 \pi f (\tau_0 - f_d/k) + 2 \pi f \cdot 2v/c \cdot iT_r \end{aligned} \quad (2)$$

It is the coupling term in the equation (2) caused a walking distance, to offset the amount of time to reflect on is $\Delta t_i = -2v/c \cdot iT_r$. Keystone transform the way is the use of variable scaling, offset by the coupling term. Specific works as follows:

First seen as a continuous variable i , define a virtual time i' , i' has the following relationship with i :

$$f_0 i' = (f_0 + f) i \quad (3)$$

Equation (3) is of particular significance: When $f = 0$ 时, i' for i , when $f > 0$ 时, i' is greater than i , and f is linear with the upcoming increased from the original due to f different phase changes, regarded with increasing time intervals i' be compensated. $F < 0$ when the situation is similar, but i' is reduced.

Meaning by a method of phase diagram can be more intuitive description of the formula (3). Equation (1) is a phase term:

$$\begin{aligned}
\varphi_o &= -\frac{\pi}{k} f_d^2 - 2\pi f(\tau_i - f_d/k) - j2\pi(f_0 - f_d)\tau_i \\
&= \theta + \frac{4\pi}{c}(f + f_0)vT_r \cdot i
\end{aligned} \tag{4}$$

Equation (4) there is nothing to move the envelope phase term:

$$\theta = 2\pi f \cdot f_d/k + 2\pi f_d \tau_i - 2\pi(f + f_0)\tau_0 - \frac{\pi}{k} f_d^2 \tag{5}$$

While the second phase term caused envelope walking factors. Readily appreciated, for different frequency components, and the corresponding Doppler frequency is different, so the rate of change of phase change, the higher the frequency corresponding to the phase change faster, slower and vice versa. If the phase change history in the form of equal phase lines drawn in the two-dimensional plane, as shown in Figure 1 (a) as shown, can be seen, and other phase lines are not parallel to each sub-domain that is move the envelope when reflected. Through the introduction of virtual time, on different frequencies to be adjusted accordingly, the frequency offset due to different phase changes caused by different rates, equal phase lines appear in the two-dimensional plane is a set of parallel lines, so that the correction in the time domain envelope around, as shown in Figure 1 (b) below.

Figure 1. Keystone transform schematics

2 Envelope compensation based on Keystone Transform

Within the limits of the radar repetition rate, the target of high-speed motion can result in severe Doppler ambiguity, since the scale transformation (or variable substitution) in the frequency domain, the Doppler ambiguity will affect the transformed envelope alignment accuracy, thereby affecting the accumulation effect. Thus, the need for Keystone conversion formula to make certain amendments.

For the true value and fuzzy values have the following relationship:

$$f_d = f_{d,amb} + F_{amb} F_r \tag{6}$$

On the basis of the existing theory can following relationship:

$$\begin{aligned}
2v(f_0 + f)/c &= 2(v_d + F_{amb}v_m)(f_0 + f)/c \\
&= f_d' + F_{amb}F_r
\end{aligned} \tag{7}$$

Envelope Keystone transform only speed relative motion caused by walking to compensate, but the package Doppler ambiguity caused by walking envelope can not be compensated by the amount of time walking due to Doppler ambiguity:

$$\Delta t_i' = \frac{2F_{amb}v_m}{c} \cdot iT_r \tag{8}$$

From the above equation, when the target speed is large, the Doppler ambiguity generated significant misalignments resulting large, if not the compensation would have serious implications

for the cumulative effect.

After Keystone conversion, frequency f_0+f corresponding to the Doppler frequency becomes:

$$2v(f_0 + f)/c = f_d' + F_{\text{amb}} F_r \frac{f_0}{f_0 + f} \quad (9)$$

So the need for the formula (7) is corrected as follows:

$$S_k(f, i') = \sum_{i=0}^{N-1} S_o(f, i) \text{sinc} \left[\frac{i' f_0}{(f_0 + f)} - i \right] \cdot \exp \left(j 2 \pi F_{\text{amb}} i' \frac{f_0}{f_0 + f} \right) \quad (10)$$

Figure 2 shows the target speed -3000m / s, the noise and SNR of 6dB, the use of Keystone transform alignment effect 256 echo pulses, showing the pulse pressure is the result of processing after contour data line graph. It can be seen from the figure, after Keystone transform the target track becomes a vertical line, the peak envelope adjusted to the same distance unit.

Figure 2. The target speed using an enveloping effect of the alignments Keystone transform when -3000m / s

Due to high velocity and low repetition frequency radar, echo Doppler ambiguity great degree unknown in the ambiguity of the situation will greatly affect the accuracy of the alignment of the envelope, thereby affecting the accumulation effect. To solve this problem, you can follow the envelope interpolated motion compensation way to obtain the Doppler ambiguity range of motion in accordance with the target speed range, according to certain steps, divided into a number of Doppler ambiguity compensation channel search again perform coherent integration and target detection. Algorithmic process similar to the interpolation motion compensation envelope, there is not specifically given, only in different places Keystone Transform and Doppler ambiguity search in the frequency domain, and then transformed into the time domain by IFFT, and then the resulting pulse pressure signal sequence coherent integration testing.

Summary

This article first elaborated the principle of Keystone transform, and then analyzed for the

presence of the Keystone transform envelope motion compensation issues, and gives the algorithm method for improving the chirp radar target motion uniformly accelerated accumulation of weak signals detection capability has laid a good foundation.

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