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A Method for Range Alignment Based on Coherent Echoes by Wideband Radar

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Abstract. The problem of range alignment in Inverse Synthetic Aperture Radar (ISAR) imaging has been discussed for many years and the methods have been successfully used in real data processing. But all these methods are based on incoherent echoes, which can't utilize the coherence of the echoes. As a result, they are of computational complexity and lead to low precision. In this paper, we propose a new method, which makes good use of coherent echoes. It uses the envelope correlation and the curve fitting, which is simple and is verified by real data.

Keywords: ISAR; range alignment; coherent echoes; curve fitting

1. Introduction

Inverse Synthetic Aperture Radar (ISAR) imaging is based on the translational motion compensation, while the translational motion compensation is based on the range alignment. The quality of the range alignment directly affects the final result of the ISAR imaging. The methods of range alignment are mostly envelope correlation proposed by C.C.Chen[1] and minimum entropy by Genyuan Wang[2] and the methods improved[3]-[9]. The envelope correlation algorithm is faster and has the same precision with the minimum entropy algorithm when dealing with each range cell. However, the minimum entropy algorithm is of computational complexity, especially when the radar has a high resolution and works under the long time integration model [3]. As a result, the envelope correlation algorithm is widely used.

In order to overcome the problem of drift errors and jump errors, improved methods are proposed, which are based on the average range profile[2][4][5]. And for the propeller-driven aircraft, method such as power transform is used, in order to weaken the affection of the bad echoes [6]. In a word, the exiting methods usually meet the need of imaging.

However, limited to the hardware technology, the radar is based on stretch system, resulting in the non-coherence of the echoes. So the exiting methods of range alignment are based on incoherent echoes. And they can't utilize the coherence of the echoes. With the development of technology, directly sampling comes true, which ensures that the echoes are coherent [10]. Based on some wideband radar data (Linear Frequency Modulation (LFM) signal, centre frequency: 9.5GHz, bandwidth: 1GHz, pulse width: 200us, pulse repeat interval (PRI): 3ms, sampling frequency: 1.2GHz), this paper studies the method of range alignment for coherent echoes, making good use of the coherence. The final result shows that the method is of great use.

2. Method of Range Alignment for Coherent Echoes

2.1. Signal model

Let's suppose that the signal transmitted by wideband radar is

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$$s(t,t_m)=u(t)\exp\{j2\pi f_c t\} \tag{1}$$

Then the received target echo for single scatter is

$$s_R(t,t_m)=u(t-\tau)\exp\{j2\pi f_c(t-\tau)\} \tag{2}$$

where $u(t-\tau)$ is the delay envelope.

Fig. 1 and Fig. 2 show the distribution of the envelopes for the same target at the same time, the radar working under the stretch model and directly sampling model, correspondingly, from which we can see the moving of the envelopes. As has been pointed out, the echoes under the stretch model are incoherent and the envelopes are irregular, while those under the directly sampling model are coherent and the envelopes are regular.

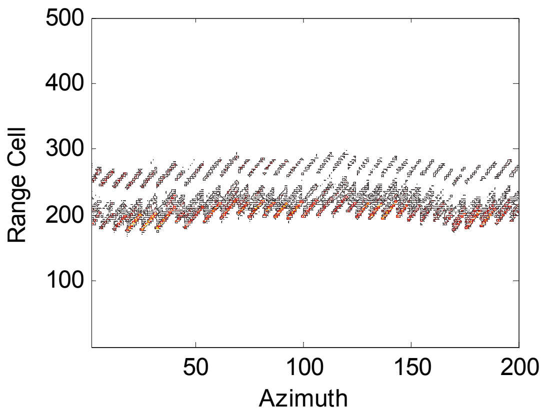

Fig. 1: The distribution of the envelopes under the stretch model

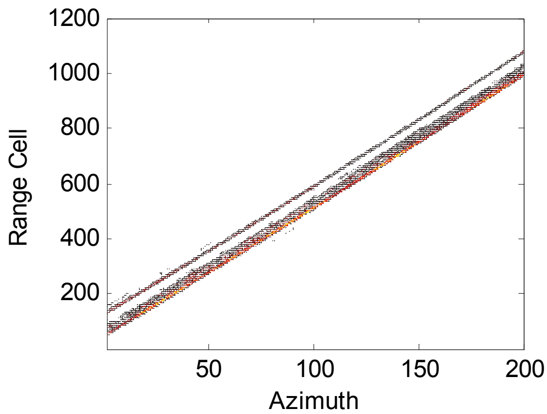

Fig. 2: The distribution of the envelopes under the directly sampling model

2.2. Envelope correlation

The envelope correlation is based on the strong relativity between the adjacent echoes. The range profiles are very similar. For two adjacent envelopes $s_m(t)$ and $s_{m+1}(t)$, the delay can be gained by

$$\tau=\arg\max s_m(t)s_{m+1}^*(t-\tau)$$

If the average range profile is used, we get [6]

$$\begin{cases} norm_1 = pro_0^v \\ norm_{m+1} = norm_m \times \eta + pro_m^v \end{cases}$$

where $norm_i$ is the ith average range profile while pro_i is the ith range profile, η is the weight factor and v is the power transform coefficient.

The traditional methods stop here, which can also lead to fine quality of range alignment. For the better, some used interpolation [10] or the super-resolution technique [11]. But they were of computational complexity. After all, they didn't utilize the coherent echoes.

2.3. Curve fitting

When dealing with the date used above using the exiting methods, we can get the delay of each envelope as the figures bellow shows:

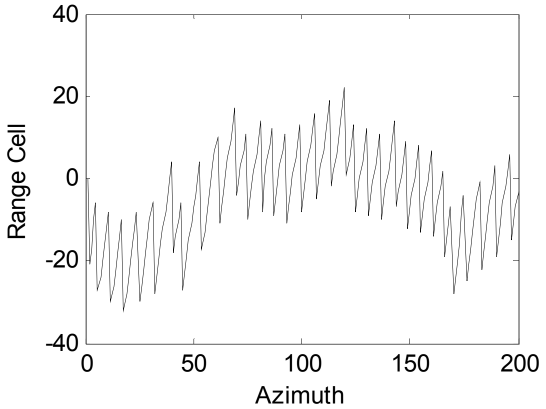

Fig. 3: The delay of the envelopes under the stretch model

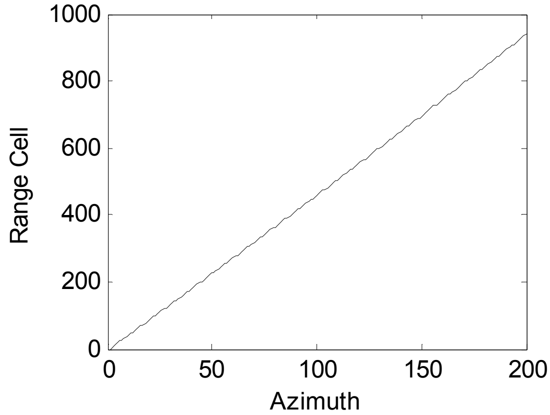

Fig. 4: The delay of the envelopes under the directly sampling model

We can see from the figures that the curve of the delay under the stretch model is irregular and can't be smoothed. Though some scholar made it, it was for low speed targets [12]. Some proposed piecewise smooth and found the period [13]. However, it was very difficult to find the exact period. But the curve of the delay under the directly sampling model is near a slick one, which corresponds to the fact, as the exiting of the inertia. The gurgitation is due to the error of the envelope correlation algorithm. So we can smooth the curve using the curve fitting. Fig. 5 shows the result. We can also plot the difference before and after the curve fitting as Fig. 6 shows. As can be seen from the figure, the errors of the envelope correlation algorithm are less than ±0.6 range cell and most are less than ±0.4. So we take the delay after the curve fitting to shift the envelopes.

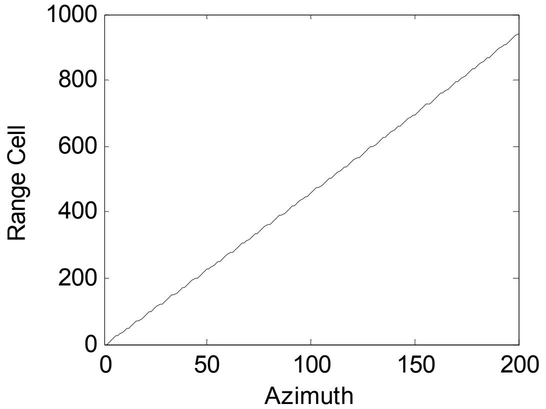

Fig. 5: The delay of the envelopes after the curve fitting

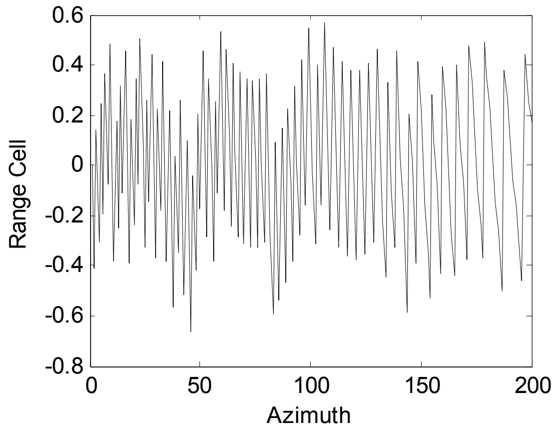

Fig. 6: The difference of the delay of the envelopes before and after the curve fitting

2.4. The frequency shift character of Fourier Transform

As the delay after the curve fitting isn't integer. So we can't simply shift the envelopes in the time domain. However, we can utilize the frequency shift character of Fourier Transform as follows [5][14]:

$$s_i(m+\tau) = ifft\left\{ fft\left(s_i(m)\right)\exp(j2\pi\tau\Delta f n T_s)\right\} \quad . \quad .$$

where $s_i(m)$ is the envelope to be aligned while $s_i(m+\tau)$ aligned, Δf is the resolution of the $ifft$, and T_s is the sampling period.

Here we show the results of the range alignment before and after the curve fitting under the directly sampling model as follows, from which we can see that the latter is better.

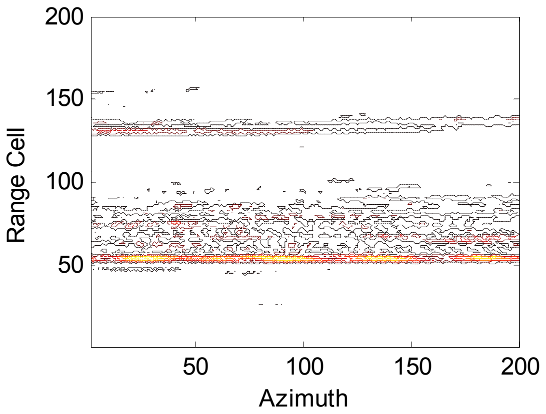

Fig. 7: Range alignment before the curve fitting

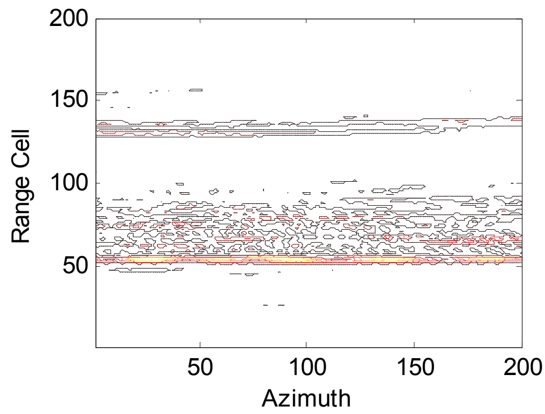

Fig. 8: Range alignment after the curve fitting

3. Results based on Real Data

This paper deal with the data above with the method proposed here to align the envelopes and with the same phase compensation method and the same imaging method. Finally, we obtain the ultimate imaging figures as bellow. As can be seen from the pictures, after the curve fitting, the result is better and the defocus along the cross range cell almost disappears.

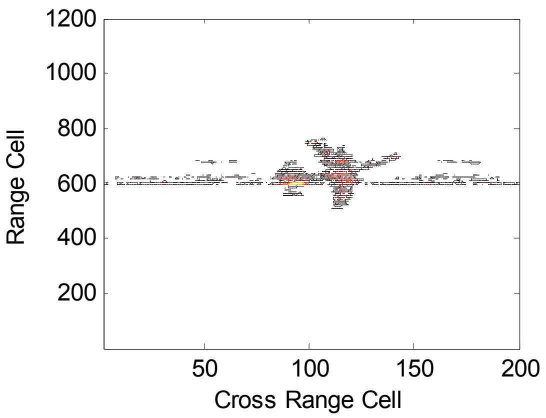

Fig. 9: Imaging before the curve fitting

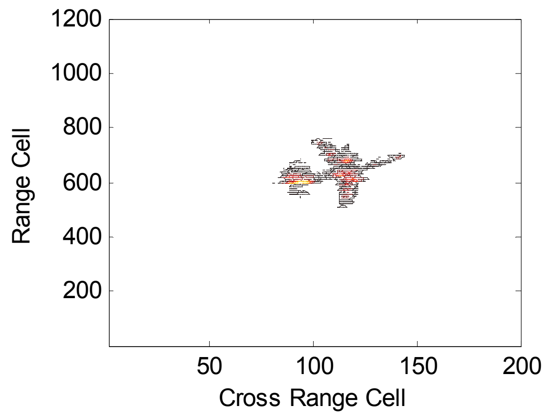

Fig. 10: Imaging after the curve fitting

4. Conclusions

This paper goes over the exiting methods for range alignment in ISAR imaging and finds that they can't utilize the radar coherent echoes. Based on the coherent echoes, we use the curve fitting after the delay is obtained by envelope correlation, which makes higher precision and leads to better imaging result. Dealing with the real data indicates that the method is powerful.

5. Acknowledgment

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BIOGRAPHY

Jianzhi Lin was born in 1987. He is currently working toward the master's degree with specialization in electronic science and technology at National University of Defense Technology. His research interests include radar signal processing and targets recognition.

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