LETTER

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The range alignment approach for signal acquisition system

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Abstract: The range alignment approach is applied to solve the misalignment between the sampling clock and trigger pulse for signal acquisition system of pulse and Doppler (PD) radar. Adjacent pulse correlation (APC) and minimum entropy (ME) methods are utilized to suppress sidelobes and promote the detection performance. Experimental results have demonstrated the effectiveness of proposed methods.

Keywords: range alignment, pulse and Doppler (PD) radar, Adjacent pulse correlation (APC), minimum entropy (ME)

Classification: Electronic instrumentation and control

References

[1] D. R. Wehner: *High Resolution Radar* (Artech House, London, 1995) 2nd ed. 46.

[2] B. T. Ma, Y. L. Zhu and H. Q. Fan: The 8th International Conference on Electronic Measurement and Instruments (2007) 673. DOI:10.1109/ICEMI.2007.4350540

[3] A. Ferrari, C. Bereguer and G. Alengrin: IEEE Trans. Aerosp. Electron. Syst. **33** (1997) 738. DOI:10.1109/7.599236

[4] G. M. Cleetus: IEEE Trans. Aerosp. Electron. Syst. **12** (1976) 800. DOI:10.1109/TAES.1976.308359

[5] J. M. Muñoz-Ferreras, J. Calvo-Gallego and F. Perez-Martinez: IEEE Conf. Radar in Proc. (2006) 366.

[6] J. Wang and D. Kasilingam: IEEE Trans. Aerosp. Electron. Syst. **39** (2003) 351. DOI:10.1109/TAES.2003.1188917

[7] L. Xi, L. Guosui and J. Ni: IEEE Trans. Aerosp. Electron. Syst. **35** (1999) 1240. DOI:10.1109/7.805442

1 Introduction

The pulse and Doppler (PD) radar can retrieve range and velocity information of illuminated targets by range suppression and Doppler coherent

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accumulation [1]. For Doppler processing, the coherence of the echoes within a coherent integral time (CIT) is necessary. Radar signal acquisition system is an indispensible instrument for radar development and performance evaluation. In radar signal acquisition, usually the sampling clock coming from radar can be divided exactly by radar pulse repetition frequency (PRF) with which the trigger pulse for data sampling is derived. That is because both sampling clock and PRF signals are frequency divided by a same highly stable oscillator [2]. However, some radars in use now haven't prepared clock for external radar signal acquisition system. Thus, the internal clock of radar signal acquisition system has to be used. However, only with this clock, it is too hard for a universal radar signal acquisition system to be adapted for all kinds of radar PRF, especially for conventional moving target indication (MTI) radars, in which PRF staggering is widely used to overcome the velocity and range ambiguity problems [3, 4]. When the sampling clock cannot be divided exactly by radar PRF or the trigger pulse has a slight jitter, which could be caused by circuit noise, the misalignment between sampling clock and trigger pulse occurs, which will lead to range bin shift. This results in a spreading of the target energy, and increasing the sidelobes in range and Doppler plane. Fig. 1 illustrates the influence of range misalignment on Doppler processing. In this paper, range alignment methods are proposed based on Adjacent pulse correlation (APC) and minimum entropy (ME) to alleviate the non-coherent effect caused by range bin misalignment.

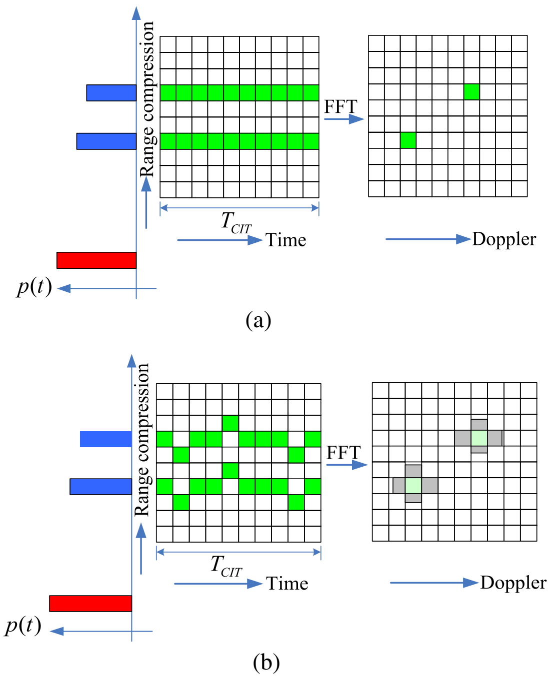

Fig. 1. Effect of range misalignment (a) Range alignment (b) Range misalignment

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2 Range alignment

After range compression, the signal within a coherent CIT can be modelled as Eq. (1) and Eq. (2).

$$\mathbf{x} = \{\mathbf{x}_1, \mathbf{x}_2, \cdots, \mathbf{x}_m, \cdots, \mathbf{x}_M\}, m = 1, 2, \cdots, M \tag{1}$$

$$x_m(t) = \sum_{p=1}^{P} A_{p,m} \operatorname{sinc}\left[B\left(t - \frac{2R_{p,m}}{c}\right)\right] \cdot \exp\left[-j4\pi \frac{R_{p,m}}{\lambda}\right] + c_m(t) \tag{2}$$

where M is the number of pulses within CIT, P is the number of targets, B is the pulse bandwidth of transmitted radar signal, c is the speed of light, λ is the wavelength. $A_{p,m}$ and $R_{p,m}$ are the reflection coefficient and range of pth target at mth pulse repetition time (PRT), respectively. $c_m(t)$ denotes the clutter and system noise. Because of the uncertainty of starting position of sampling instant at each PRT, the signal becomes as Eq. (3).

$$x'_m(t) = \sum_{p=1}^{P} A_{p,m} \operatorname{sinc}\left[B\left(t - \frac{2(R_{p,m} + \Delta R_{p,m})}{c}\right)\right] \cdot \exp\left[-j4\pi \frac{R_{p,m} + \Delta R_{p,m}}{\lambda}\right] + c'_m(t),\ \ \Delta R_{p,m} \in [0\, \Delta R_{\max}] \tag{3}$$

where $\Delta R_{p,m}$ represents the shifted range at mth PRT, $\Delta R_{\max}$ is the maximum shifted range, which is decided by the time relationship between the radar sampling clock and trigger pulse.

In this letter, adjacent correlation and minimum entropy are utilized for range alignment, which are widely used in ISAR imaging, where it is necessary to compensate the translational motion of the target in order to obtain focused images [5, 6, 7].

Because there is very little change of target motion between two adjacent pulses, the envelopes of two adjacent echoes have high correlation. The maximum correlation is used as the criterion of correlation algorithm. Let $x'_m(t)$ and $x'_{m+1}(t)$ be the recorded complex return echo from adjacent pulses. The correlation function between two adjacent echoes is defined as Eq. (4).

$$R(\tau) = \frac{\int |x'_m(t)||x'_{m+1}(t-\tau)|dt}{\left(\int x'^2_m(t)dt \int x'^2_{m+1}(t)dt\right)^{1/2}} \tag{4}$$

Varying τ, the location of the peak of $R(\tau)$ gives to estimate range bin shift required to realign the range bins. In such a way, we can estimate the range bin shift pulse by pulse. In order to improve the accuracy of adjacent correlation, the APC can be implemented in frequency domain where interpolation can be used.

On the other hand, maximum sharpness of the synthetic envelope can also be used as the criterion to determine the range bin alignment. If all the echoes have already been accurately aligned, the synthetic envelope has the highest sharpness. Otherwise the sharpness reduces. The entropy is a criterion to measure sharpness of a signal. The entropy of a signal sequence $\mathbf{y} = \{y(1), y(2), \cdots, y(n), \cdots, y(N)\}$ is defined as Eq. (5).

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$$H(\mathbf{y}) = \sum_{n=1}^{N} p_n \log p_n \tag{5}$$

where $p_n = |y(n)|/\|\mathbf{y}\|$, $\|\mathbf{y}\| = \sum_{n=1}^{N} |y(n)|$. Define the adjacent synthetic envelope as Eq. (6).

$$\mathbf{y}(m+1,\tau) = \mathbf{x}_m + \mathbf{x}_{m+1,\tau} \tag{6}$$

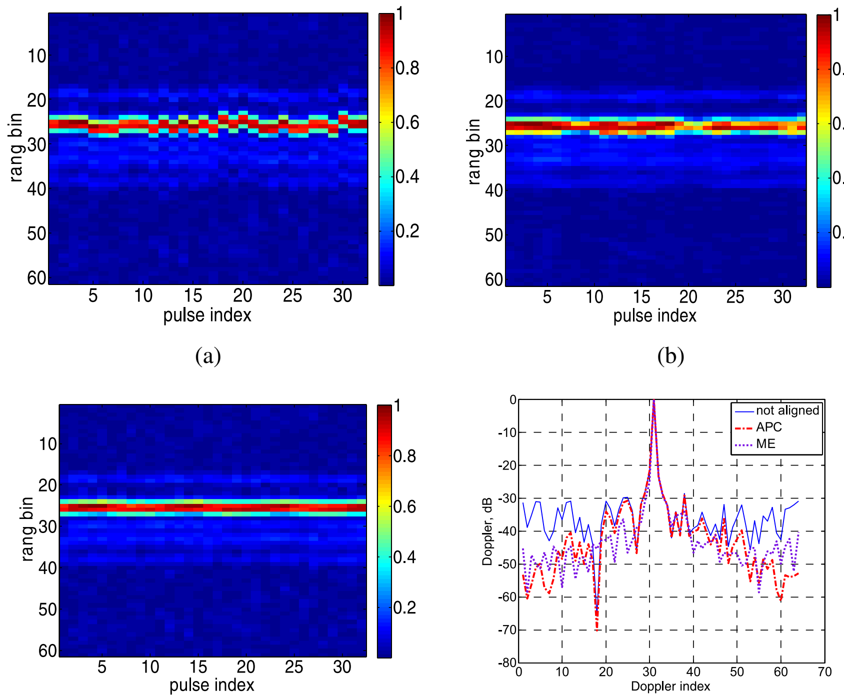
$\mathbf{y}(m+1,\tau)$ is obtained by sum of the mth echo and the $m+1$th echo with the time delay τ. The misalignment of the range bin is determined by τ, which can be obtained by minimizing the $\mathbf{y}(m+1,\tau)$'s entropy as Eq. (7).

$$\tau_{m+1} = \min_{\tau}\{H(\mathbf{y}(m+1,\tau))\} \tag{7}$$

All the envelopes of the echoes can be aligned by this way pulse by pulse. After range bin alignment, the FFT can be applied to every range bin to obtain the Doppler information of the targets.

3 Experimental results

The proposed methods were evaluated using the experimental data recorded from PD radar for detecting the ships in the sea. When recording the radar data, the range bin shifts because of the misalignment and jitter between radar signal sampling clock and trigger pulse. The CIT contains $M = 64$ pulses and the number of range bin is $N = 60$. The signal to noise ratio (SNR) before Doppler coherent processing is 12 dB. There is a ship in the



(c) (d)

Fig. 2. Range alignment results (high SNR) (a) Range compression (b) Range alignment by APC (4 times interpolation) (c) Range alignment by ME (d) FFT result at range bin 26

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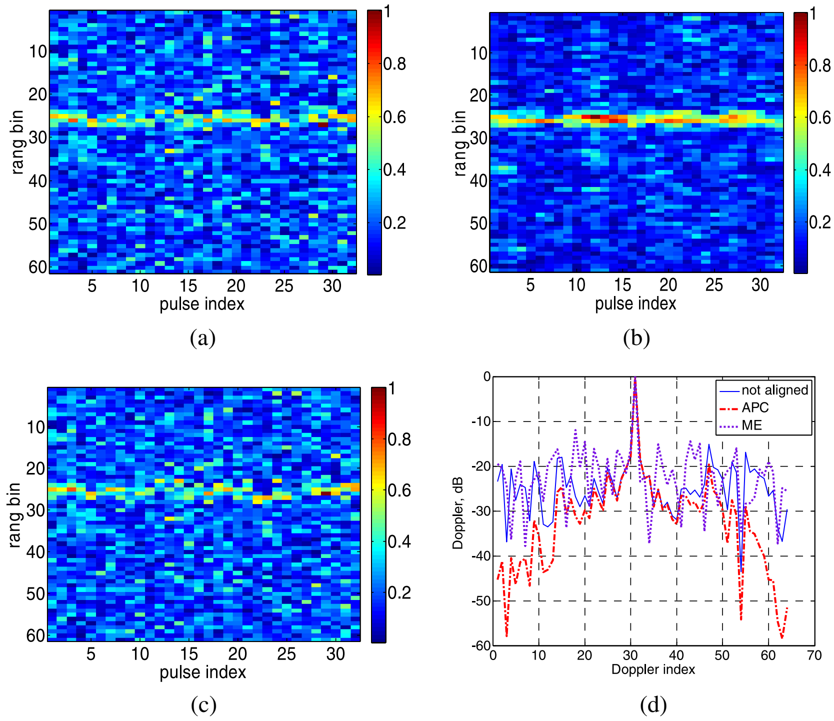

Fig. 3. Range alignment results (low SNR) (a) Range compression (b) Range alignment by APC (4 times interpolation) (c) Range alignment by ME (d) FFT result at range bin 26

range bin 25 and 26. Fig. 2(a) depicts the result after range compression, we can see that range bins are randomly shifted. After APC (4 times interpolation) and ME alignment, the alignment results of first 32 pulses are shown in Fig. 2(b) and Fig. 2(c). Fig. 2(d) demonstrates the Doppler spectrum of the target. It is shown that the sidelobes are relatively high because of range misalignment. Both APC and ME alignment can significantly reduce the sidelobes, while the ME alignment method has about a 3∼5 dB sidelobe suppression improvement in the Doppler bins around the target compared with the APC in such a high SNR situation. Secondly, the alignment performance was evaluated in lower SNR situation. The Gaussian white noise was added to the real data and the SNR before coherent processing is set as 2 dB. Fig. 3(a), Fig. 3(b) and Fig. 3(c) demonstrate the results before and after alignment by the methods proposed of the first 32 pulses. Fig. 3(d) shows the Doppler spectrum of the target. It can be shown that ME method fails in such low SNR situation, while APC is still effective to align the range bin. And APC is more robust than ME method in low SNR.

4 Conclusion

In this paper, adjacent pulse correlation and minimum entropy are used for range alignment in radar signal acquisition system. The effectiveness of proposed methods is assessed in different SNR by experimental results.

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