

A Novel CAF Based on Multirate Signal Processing and Envelope Shift Compensation

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Abstract. Passive radar can be used for aircraft surveillance, the principle of which is achieving energy integration of the moving target echo with the help of Cross Ambiguity Function (CAF). In this paper we present a new calculation method of CAF based on multirate signal processing and envelope shift compensation. Multirate signal processing being adopted before CAF computing can improve the measurement precision of time delay by increasing the sampling rate of the direct signal and target echo signal in baseband. When the broadband digital video broadcast (DVB) signal is used as illuminator, the longer the integration time is, the more severe the range migration will be which will greatly decrease the signal integration gain, envelope shift compensation being adopted in this method can improve the integration gain by refocusing the energy of the target echo. The simulation results reveal that the proposed method can improve the measurement precision of the time delay and the integration gain efficiently.

Keywords: Cross Ambiguity Function, multirate signal processing, range migration

1. Introduction

Passive radar is a variant of bi/multi-static radar systems that exploit non-cooperative illumination sources such as TV and FM radio as their transmitter [1,2,3,4,5], a diagram of typical configuration is shown in Fig.1. Passive radar is beneficial for the detection of stealth aircrafts and cruise missiles, thus it has become an important equipment being developed in many countries today. DVB signal has many attractive features such as stability, wide bandwidth and low sidelobe of ambiguity function[3,6], that classify DVB signal to be an ideal illumination source. While analog TV is gradually replaced by digital TV, an upsurge is witnessed in the study of digital TV based passive radar.

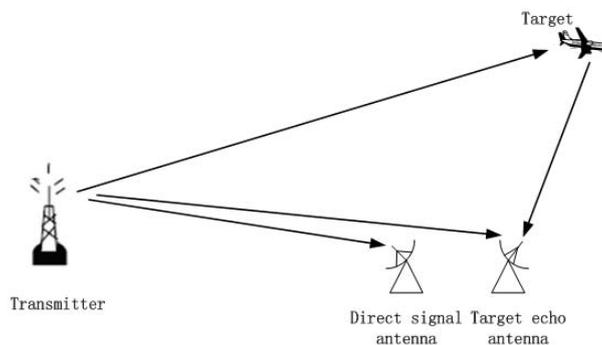


Fig. 1: The diagram of typical configuration of passive radar.

Passive radar integrates the energy of moving target echo by cross ambiguity function which can be written as

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$$A(\tau, f) = \int d(t + \tau)r^*(t) \exp(-j2\pi ft)dt \quad (1)$$

where $r(t)$ represents the direct signal from the bistatic transmitter, $d(t)$ is the target echo, τ is the time delay and f is the Doppler frequency.

When analog signal is converted to discrete digital signal, (1) is expressed as

$$A(\tau, k) = \frac{1}{N} \sum_{n=0}^{N-1} d(n)r^*(n + \tau) \exp(-j2\pi \frac{kn}{N}) \quad k = 0, 1, \dots, N-1 \quad (2)$$

Long time coherent integration is an effective way to improve the performance of moving target detection. In the scenario of DVB signal based passive radar, where the bandwidth of the DVB signal is wide, during long time coherent integration, the target echo may migrate across radar range cells, a phenomenon called range migration, which is caused by the velocity of target. Migration will lead to dispersion of the target peak energy in the output of CAF, which reduces the signal to noise ratio (SNR), making it impossible to detect weak target at long distances with high speed.

C. C. Chen proposed the envelope alignment method for migration compensation in his literature in early 1980s, and since then significant research has been done by many domestic and international scholars [7-10] in this regard. A lot of compensation methods have been mentioned in literature, such as coherent integration algorithm based on Fractional Fourier transform and envelope interpolation[9], coherent integration algorithm based on Fractional cross ambiguity function and keystone transformation[8,10], etc. However, the implementation of these algorithms is very complicated especially in practical realization.

This paper proposes a CAF based on multirate signal processing, which increases the sampling rate of the direct signal and target echo signal in baseband to improve the measurement precision of the time delay, and then proposes a range migration compensation method based on envelope shift.

This paper is arranged as follows. In the second part, a method based on multirate signal processing is proposed to improve the measurement precision of the time delay; a method for range migration compensation based on envelope shift is proposed in the third part; and the fourth part is conclusion.

2. CAF Based on the Multirate Signal Processing

For passive radar, the maximal time delay error is defined as follows:

$$\Delta t = 1/2f_s \quad (3)$$

where f_s is the sampling frequency. From (3), the time delay precision can be improved by increasing sampling rate of the baseband signal.

The schematic diagram of the CAF based on multirate signal processing is drawn in Fig.2. The sampling rate in baseband of the direct signal and target echo signal is increased by using a technique employing interpolation of digital signal. In practice, since the sampling rate is far greater than the Doppler frequency of moving target, if we compute FFT of the result of complex multiplication, most of the frequency band is void of where target seems to appear, so decimation can be used before FFT to reduce the computation time.

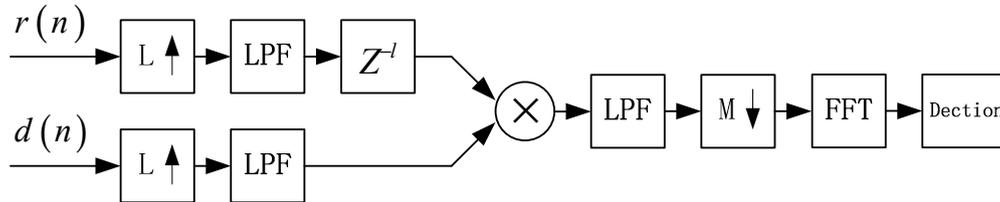


Fig. 2: The schematic diagram of the CAF based on multirate signal processing.

A simulation is carried out to compare the time delay precision of target between the (2) and the CAF based on multirate signal processing proposed in this paper. Simulation parameters are as follows: the sampling rate in baseband is 9MHz, the integration time is 0.4s, the interpolation factor $L=2$ and the target delay is 150.5 baseband sampling periods (i.e. $16.72 \mu s$). Fig.3(a) is the CAF without interpolation, the time delay is estimated as 151 sampling periods (i.e. $16.78 \mu s$), there is a little error between the measurement

value and the actual value caused by the lower sampling rate in baseband. Fig.3(b) is the CAF based on multirate signal processing, the baseband sampling rate is increased to 18MHz after interpolation, the time delay is estimated as 301 sampling periods(i.e. $16.72 \mu s$).

Simulation results imply that the method proposed in this paper can effectively improve the time delay measurement precision.

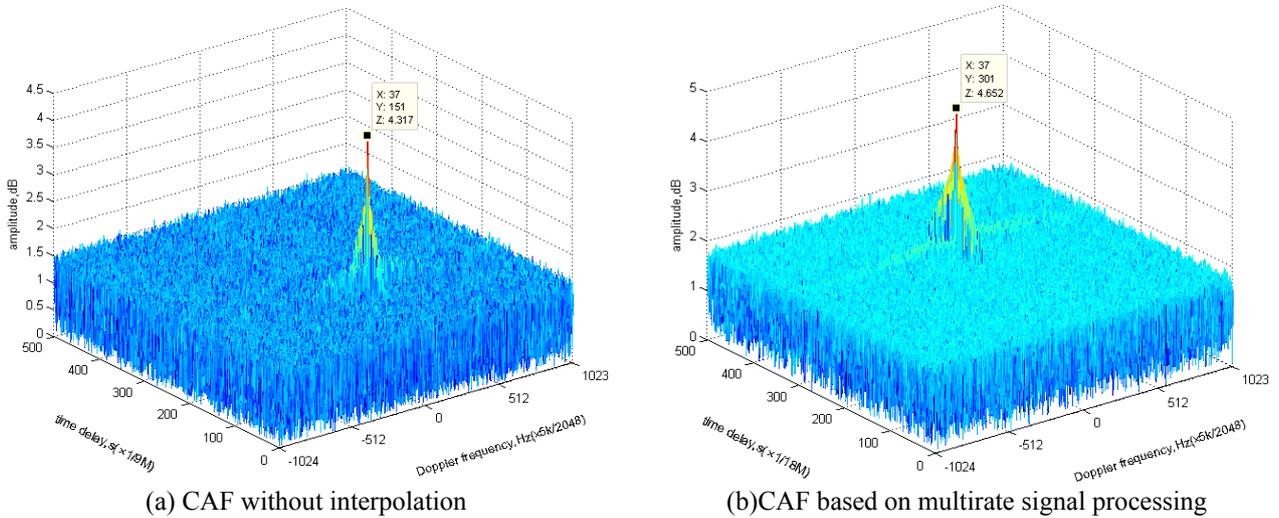


Fig. 3: Comparison of the time delay measurement precision.

3. CAF Based on Envelope Shift

Since in the case of passive radar based on FM radio or audio signal of analog TV, the bandwidth of the signal is quite narrow, the integration time can be 2s or longer.

However, in the passive radar based on DVB signal, the bandwidth of the signal is more than 7.5MHz, hence the integration time is reduced to around 0.1s (concerned with the radial velocity of the target), which affects the integration gain badly.

If the integration time is increased to more than 0.4s, the target motion will lead to relatively large range and Doppler migration, as shown in Fig.4, which will cause a decline in the integration gain if no compensation method is employed.

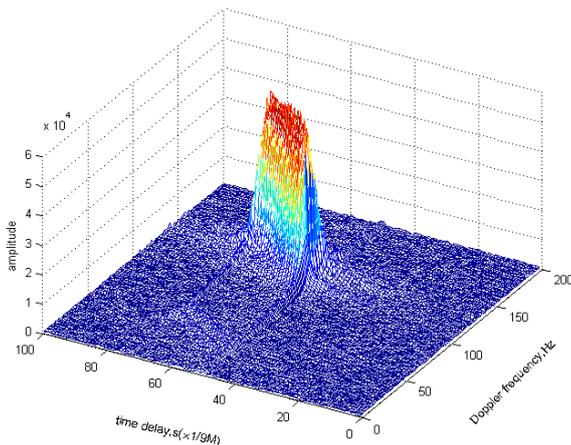


Fig. 4: The range and Doppler migration.

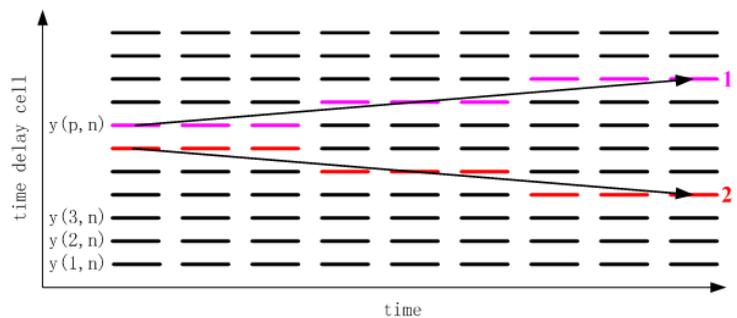


Fig. 5: The diagram of the envelope migration.

The range migration is caused by the velocity and acceleration of the target, taking into account that the actual target acceleration is very low and has little effect on the integration gain, so we assume the range migration is mainly caused by the velocity of the target.

As illustrated in Fig. 5, a two-dimensional matrix is got by doing complex multiplication of the direct signal and the target echo signal with time delay. Assume that the target energy is equally distributed into three range cells, along with the direction of the arrow as presented in Fig. 5. Line 1 shows that the range

unit increases when the target flies far away and Line 2 shows that the range unit decreases when the target flies near close.

The key idea of the envelope shift compensation is to recompose data along the direction of envelope migration and re-focus the energy of the target echo.

Steps in detail are listed as follows:

- 1) Do correlation of the direct signal and the target echo signal with time delay, as shown in Fig. 5;
- 2) Estimate the curve of envelope migration according to the possible velocity of the target;
- 3) Compute the FFT of the data on the curve. Then one range cell is computed out and the CAF can be obtained by computing multi range cells.

A simulation is carried out to analyze the performance of the CAF based on the envelope shift.

Experimental parameters are as follows: the baseband sampling rate is 9MHz, the integration time is 0.4s and the radial velocity of target is 125m/s. The CAFs with and without compensation are presented in Fig. 6.

The SNR of the target with and without compensation is 32.8dB and 35.8dB respectively.

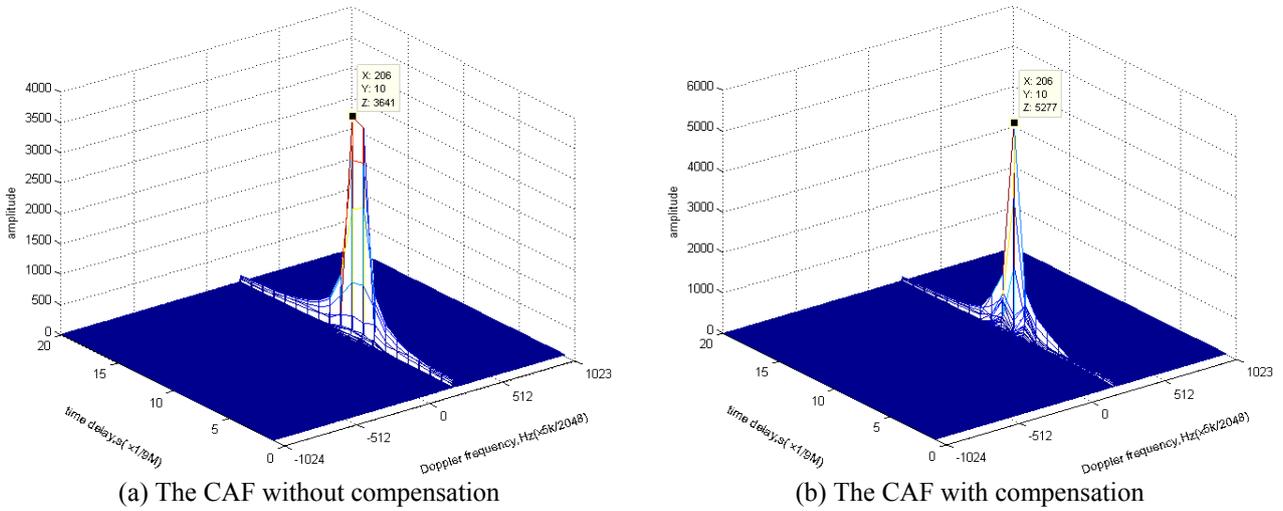


Fig. 6: Comparison of the CAFs with and without compensation.

It can be seen from the simulation results that, after the range migration compensation based on envelope shift is employed, the integration gain is **increased** and the SNR of target is improved for about 3dB.

The multirate signal processing based CAF can effectively improve the measurement precision of the time delay. If the method is applied with the range migration compensation based on envelope shift, the coherent integration gain will be improved. The schematic diagram of the CAF proposed is shown in Fig. 7.

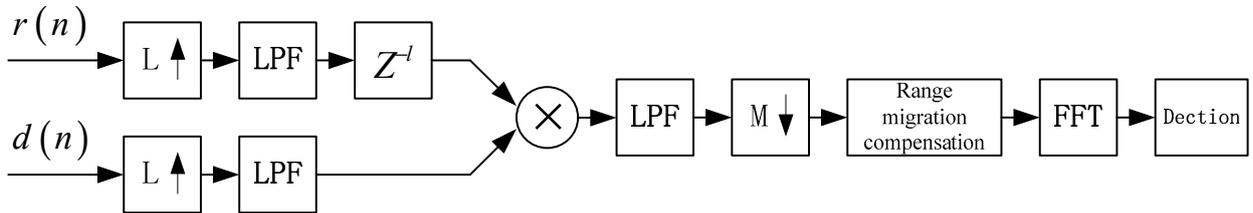


Fig. 7: The schematic diagram of the CAF based on multirate signal processing and envelope shift.

The experimental data is used to verify the CAF based on multirate signal processing and envelope shift proposed in this paper, where the baseband sampling rate is 9MHz and the integration time is 0.8s. The CAF without interpolation and range migration compensation is shown in Fig.8(a) where the range of the time delay is 4000~4050 sampling periods, the time delay of the target is 4019 sampling periods(i.e.446.56 μs) and the SNR is 16.9dB. The CAF based on multirate signal processing and envelope shift is presented in Fig.8(b) where the interpolation factor $L=2$, the range of the time delay is 8000~8100 sampling periods, the time delay of the target is 8034 sampling periods(i.e.446.33 μs) and the SNR is 20.3dB.

The experimental data analysis indicates that the method proposed can improve the coherent integration gain of about 3.4dB and effectively increase the measurement precision of the time delay by using multirate signal processing.

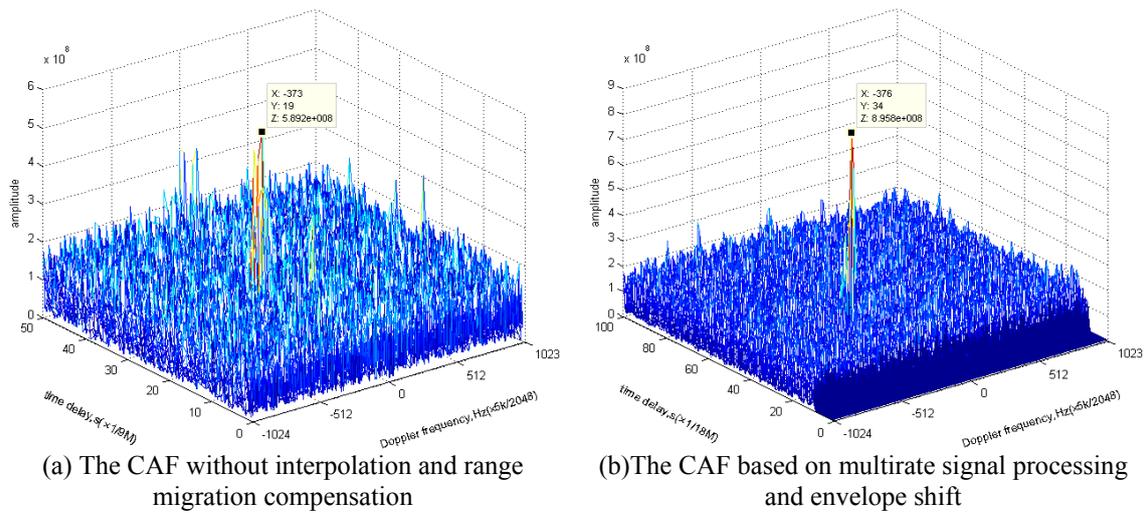


Fig. 8: Comparison of the CAFs with and without multirate signal processing and envelope shift.

4. Conclusions

Taking aforementioned fact into consideration, in this paper a novel CAF method is proposed by combining multirate signal processing and envelope shift based range migration compensation. Simulation and experimental data analysis demonstrate that the new method can improve the integration gain, the measurement precision of the time delay and the SNR of the target, which contribute to the improvement of the range of passive radar based on DVB signal.

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6. References

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