Frequency-domain Broadband Beamforming in Maneuvering of Passive Towed Linear Array

Xuefeng Gu

College of Naval Architectcture and Ocean Engineering, Naval University of Engineering, Wuhan, 430033, China

Keywords: Passive towed line array; maneuvering process; frequency domain wideband beam

Abstract: In order to further improve the performance of towed linear array, the frequency domain broadband beamforming in the maneuvering process of passive towed linear array is analyzed and studied. The research shows that the motion of towed linear array can cause the distortion of the array, thereby reducing the spatial processing gain of the drag line array sonar and increasing the error of the sonar estimation of the target azimuth. In addition, by selecting the appropriate diagonal loading value, the influence of insufficient number of snapshots can be overcome, thereby realizing a robust wideband beam with higher array gain, effectively performing spatial processing of the signal, and improving transmission performance.

1. Introduction

The towed line array is the main equipment for remote detection of underwater targets. In phased array systems, Digital Beamforming (DBF) is one of the key technologies that directly affects the performance of the entire system [1]. If the traditional narrow-band beamforming technique is applied to the wideband signal, it will cause problems such as beam pattern distortion and effective resolution reduction. Therefore, it is necessary to find a method for wideband signal beamforming [2]. If the traditional narrow-band beamforming technique is applied to the wideband signal, the beam pattern distortion and the effective resolution are reduced. As the underwater target radiated noise decreases, the passive sonar's towed line array becomes longer and longer [3]. Fractional Fourier Transform (FRFT) is a more general form of DFT and is more widely used [4]. There is no difference in principle between radar system and DBF technology in EW system, but EW reconnaissance system is a broadband system without prior knowledge of received signal, so broadband beamforming method must be applied to it to increase the instantaneous bandwidth of the system [5]. The commonly used digital broadband beamforming technology is divided into time-domain method and frequency-domain method. The time-domain method uses delay lines after each element to form FIR filters. The effect is good, but the weights are updated and the filtering operation is heavy, the sampling rate of the front-end of the system is high, and the engineering implementation is difficult [6].

However, the tactical maneuvering of towed linear array sonar will cause the distortion of its towed linear array, which will reduce the spatial processing gain of towed linear array sonar, offset the advantages of long towed linear array sonar, and increase the error of sonar to target azimuth estimation [7]. This technique can overcome the adverse effects caused by the limited number of snapshots, effectively modify the spatial spectrum estimation matrix, and enhance the robustness of beamformer [8]. The two methods have their own advantages and disadvantages. Among them, the frequency domain method has a wide range of practicability and versatility, can be combined with Digital Channelization processing, and has more advantages than the time domain method in multi-beam processing. At the same time, the frequency domain method has relatively low requirements for the front-end of the system and is more suiTable for engineering implementation, so it is more in line with the requirements of the performance of electronic warfare system [9]. In addition, the presence of strong spatial interference can seriously affect subsequent radar signal processing. Therefore, wideband beamforming is the core of wideband phased array radar signal processing and the basis for high resolution imaging. According to the first section, the real-time array element position coordinates of the tow line array in the maneuvering process can be obtained [10]. Through the force analysis of the towed line array, the motion model in seawater is established and the position of the array element is solved.

2. Methodology

Based on the above cognition, according to the idea of projection distortion of matrix distortion, a description method of formation space distortion based on parabolic model and exponential distortion model is proposed. In fact, the method of calculating FRFT by FFT algorithm is discussed in many literatures. Some algorithms calculate the FFT of large points by selecting zero or interpolation of the sequence and selecting the closest line to FRFT for approximate calculation. In the adaptive beamforming process, the sampled spectral matrix SX is estimated from data samples. The limited number of snapshots is equivalent to increasing the correlation between interference and interference and noise, resulting in a decline in adaptive beamforming performance. Therefore, it is particularly important to study a robust wideband beamformer. To overcome this shortcoming, this paper proposes an improved method of overlapping DFT based on conventional frequency domain broadband beamforming, which effectively solves the problem of periodic distortion of output waveform in time domain. Block DFT transform has less computational complexity, but the data in the range direction after filtering are not continuous in frequency domain, so it is impossible to process the frequency domain pulse compression directly. Further analysis also shows that this method will distort the subsequent pulse compression results and affect the high resolution imaging processing.

Compared with the ideal spatial gain, Fig. 1 gives the linear array assumption and uses the proposed array estimation algorithm to deal with the loss of spatial gain in these two states.

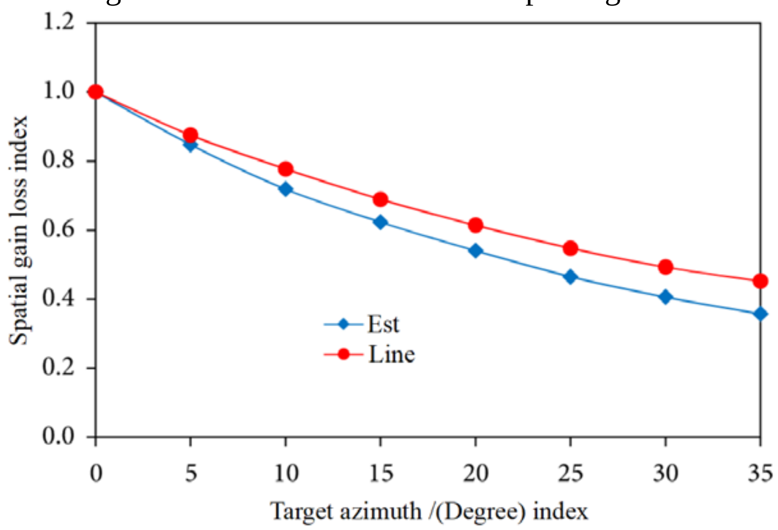

Fig.1. Linear Array Hypothesis and Element Position Estimation Time Processing Gain Loss Curve

In broadband communication systems, the characteristics of multiple frequency components and wide band range lead to the misalignment of the direction of arrival of the interference signal and the null position of the beam pattern. And the mismatch between the desired signal and the steering vector makes the SINR of the received signal decrease, and the performance of the traditional narrowband beamforming technology decreases greatly. Although the sliding window DFT method guarantees the pulse compression performance, it has a large amount of computation. The performance and computational complexity of the improved algorithm are analyzed. Although the improved algorithm increases the computational complexity of the beamformer, it is necessary to ensure the performance of the system and can be considered in the tradeoff between computational complexity and performance. The diagonally loaded beam pattern has better robustness, can overcome the error caused by the limited number of samples, can effectively form a broadband beam in the desired direction, and can effectively suppress the sidelobe level. Whether it is a beam or a split beam, multi-beamforming is very convenient to process using FFT, and the computational efficiency is much higher than the direct calculation. The simulation processing and verification on the actual sonar signal processor platform indicate this. The position of the array elements is estimated mainly by using the attitude sensor information or the sonar platform maneuver information.

Figure 2 shows the output target azimuth deviation between linear array and formation estimation in the range of 0~170°. The matrix estimation with respect to the linear matrix is improved in both the azimuth estimation accuracy and the spatial processing gain.

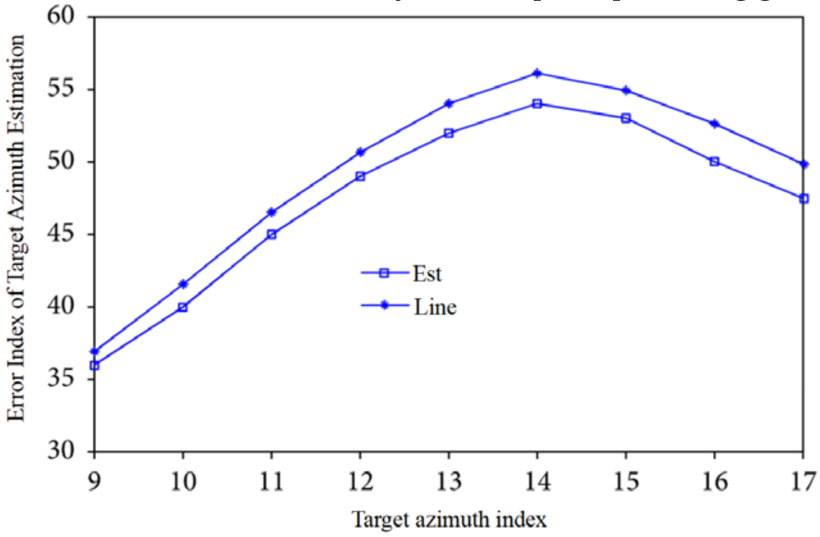

Fig.2. Beam azimuth deviation curves in the range of 0-170 degrees for linear array hypothesis and element position estimation

3. Result Analysis and Discussion

The main factor affecting the sonar performance of towed linear array is array distortion. This kind of algorithm needs to add attitude sensors in the array. Its characteristic is that it is not limited by the signal-to-noise ratio of target radiated noise and the hydrodynamic model, and it can be realized in engineering. For linear arrays, the two-time FFT (2D-FFT) algorithm is only an approximate calculation for sinusoidal coordinate broadband multi-beamforming. The receiver first downconverts all kinds of electromagnetic signals received by each element in a certain frequency band to a specific intermediate frequency through radio frequency processing, and then digitizes them and caches them. The algorithm first performs a continuous FFT transform on the data, and then subdivides the frequency cabinet into broadband beamforming processing. Researchers are beginning to consider segmenting wideband signals and performing narrowband beamforming in each subband. Since the entire bandwidth is divided into M frequency bins, the bandwidth and center frequency of each frequency cabinet are the same as the conventional algorithms. This will bring errors to subsequent signal detection in the time domain, ultimately affecting the sorting and identification of the signal. Windowing in the frequency domain appears as a convolution operation in the time domain, which results in an error between the obtained beam output time series and the ideal output.

Assuming that the transmitter knows the channel information, the transmitting system can perform channel equalization and beamforming on the signal in the frequency domain before the IFFT after constellation mapping to counter the channel fading and multi-antenna delay effects. The simulation model of the above multi-antenna OFDM modulation and demodulation system is built. The key parameters of the model are as follows.

Table 1 Simulation parameters of multi-antenna OFDM traffic system

OFDM The Ratio of Signal Bandwidth to Carrier Frequency	0.1
Number of subcarriers	1024
Constellation Mapping	16QAM
Number of subcarriers loaded with data	890
Cyclic prefix ratio	1/4
Cosine window roll-off coefficient	1/32
Rice Factor (dB) of Rice Channel	20
Number of transmit antennas	4,6,8,16
Number of Receiver Antennas	1

Beamforming technology can be divided into transmitting beamforming and receiving beamforming. At present, the research of beam forming technology is multi-centralized receiver. By using the proposed algorithm, better sidelobe performance can be obtained. Dividing the sampled data stream into batches is equivalent to truncating the data with rectangular window in time domain. The actual spectrum corresponding to each batch of finite length data should be infinitely wide. DFT is a process of signal conversion from time domain to frequency domain. However, the beamformer only takes the limited frequency band for subband beamforming, which is equivalent to adding a rectangular window in the frequency domain. In order to implement a wideband beamformer, nested arrays have been designed, and DFT beamformers and FIR beamformers are commonly used, as well as some broadband beamforming methods that rely on focusing techniques. For the case of fewer array elements, FRFT' s fast algorithm no longer has advantages, but considering that the current DSP is optimized for implementing FFT in both hardware and software, and modern sonar signal processing is mostly done in the frequency domain. Features, this algorithm is still available as an option. Currently, models for engineering applications are mostly based on this type.

4. Conclusion

In this paper, based on the hydrodynamic mathematical model, the differential iterative method is used to estimate the position of the array element and apply it to beamforming. The description method of formation space distortion based on parabolic model and exponential distortion model is given. Combining the information of heading angle and pitch angle, a three-dimensional array estimation algorithm with strong robustness is proposed. This paper only discusses the application of LOFAR' s fast algorithm in beamforming. In fact, its application is very extensive, even in sonar signal processing. For broadband signal beamforming, the signal can be changed to frequency domain processing. Then the adaptive narrowband processing algorithm is used for different frequency cabinets, and the diagonal loading technology is used to overcome the influence of limited snapshots. The range of loading value is deduced. The simulation results show that a robust beam with high array gain can be obtained by choosing the appropriate number of snapshots and loading value. At present, there are relatively few papers based on DBF technology in electronic warfare system. However, there are still many problems to be discussed in the application of DBF to EW system, such as how to improve the instantaneous bandwidth of beamformer, the influence of inconsistent frequency response of broadband channel on DBF system, and large data transmission.

References

[1] Chi C, Li Z, Li Q. Fast Broadband Beamforming Using Nonuniform Fast Fourier Transform for Underwater Real-Time 3-D Acoustical Imaging[J]. IEEE Journal of Oceanic Engineering, 2016, 41(2):249-261.

[2] Mbaye M, Moussa D, Mboup M. LU based Beamforming schemes for MIMO systems[J]. IEEE Transactions on Vehicular Technology, 2016:1-1.

[3] Fischer J, Valeau V, Brizzi L E. Beamforming of aeroacoustic sources in the time domain: An investigation of the intermittency of the noise radiated by a forward-facing step[J]. Journal of Sound and Vibration, 2016, 383:464-485.

[4] Feng Z G, Yiu K F C, Nordholm S E. Performance Limit of Broadband Beamformer Designs in Space and Frequency [J]. Journal of Optimization Theory and Applications, 2015, 164(1):316-341.

[5] Wincza K, Staszek K, Gruszczynski S. Broadband Multibeam Antenna Arrays Fed by Frequency-Dependent Butler Matrices [J]. IEEE Transactions on Antennas and Propagation, 2017:1-1.

[6] Coviello C, Choi J, Collin J, et al. Passive acoustic mapping of sTable and inertial cavitation during ultrasound therapy[J]. The Journal of the Acoustical Society of America, 2014, 136(4):2300-2300.

[7] Hu P, Shen M, Liang C, et al. An Efficient Broadband Adaptive Beamforming Algorithm Based on Frequency–Space Cascade Processing[J]. Circuits Systems & Signal Processing, 2017, 37(1):1-12.

[8] Fu Z H. Constrained minimum power combination for broadband beamformer design in the STFT domain [J]. Frontiers of Computer Science, 2017, 11(3):408-418.

[9] Ye X, Zhu D, Zhang Y, et al. Analysis of Photonics-Based RF Beamforming With Large Instantaneous Bandwidth[J]. Journal of Lightwave Technology, 2017, 35(23):5010-5019.

[10] Yang B I, Ying-Min W, Qi W. Research on Dual Optimized Broadband Beamforming Algorithm [J]. Acta Armamentarii, 2017, 38(8):1563-1571.