Line Spectrum Comparison Method Based on LOFAR Spectrum Feature

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Abstract. Feature extraction of underwater targets and line spectrum comparison are the key of the target fusion. The changing characteristics of the ocean noise field and individual differences of receiving arrays make the line spectrum feature extraction of underwater target unstable, which leads to the target comparison misjudgment. To improve the correct rate and stability of the sea target similarity judgment, this paper presents a method of target similarity judgment based on the LOFAR spectrum feature. It extracts line spectrum feature information from the LOFAR spectrums of ship radiated noise, calculates the area of the peaks extracted out, extends peaks and finally get the judgment result using the multiple asymmetric comparison method. This paper applied this method to the multi-type target data measured at sea and obtained satisfactory effect.

Introduction

Currently feature extraction is mainly focused on extraction of the traditional DEMON and LOFAR-based feature and extraction of the characteristics based on modern signal processing technology [1]. LOFAR spectrum analysis is one of the most representative passive sonar signal processing methods [2]. LOFAR spectrum acquisition can refer to [3][4]. When the same underwater acoustic target is detected simultaneously by more than one receiving array, it needs to fuse the target by comparing the LOFAR spectrum characteristic of the target signal. Thus, comparison of LOFAR line spectrum characteristic of underwater acoustic targets is a more important section of the target fusion. Due to the individual difference of the receiving arrays, the signals received are different and its stability is different, which results in unstable LOFAR line spectrum. Judging from the human point of view, if the main line spectral overlap or close to with each other, it’s usually considered that the similarity is high. Because of the uncertainty of the secondary line spectrum, the number of the peaks extracted is not the more the better. This paper puts forward a new method of line-spectrum comparison based on LOFAR for underwater acoustic target fusion.

The target fusion process based on comparison of LOFAR line spectral feature mainly includes LOFAR spectrum preprocessing, line spectrum extraction and extension, line spectrum comparison using the multiple asymmetric comparison method and threshold determination. The flowchart of the target fusion process is illustrated in Fig. 1.

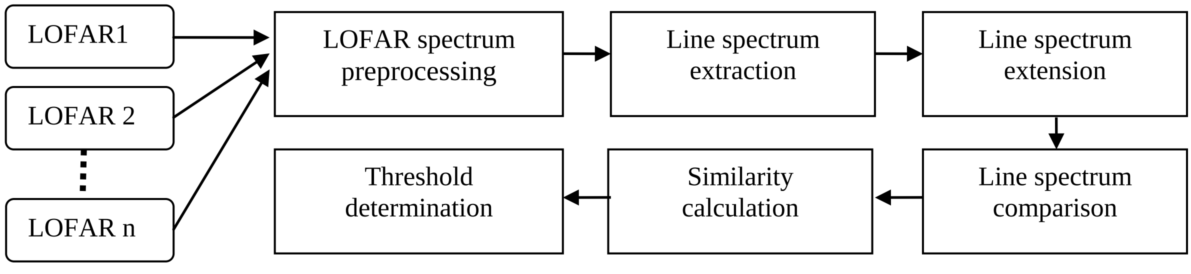


Fig.1 The Flowchart of Target Fusion

LOFAR Spectrum Preprocessing

This paper adopts a bilateral α filter algorithm to set the adaptive threshold to get the continuous spectrum after smoothing the LOFAR spectrum. Subtract the original LOFAR spectrum by the continuous spectrum to get the flattened spectrum.

The main principle of the bilateral α filter algorithm is as follows: put the data through the α filter forwards and backwards, add the output from the filter together up, multiply the sum by constant c to get the final threshold η. The output of the forward α filter and the backward α filter are respectively shown as Eq. 1 and Eq. 2. The final threshold is $\eta = c * (\hat{x}(k) + \hat{y}(k)) / 2$ [5].

$$\hat{x}(k) = (1 - \frac{1}{M})\hat{x}(k-1) + \frac{1}{M}x(k) = (1-\alpha)\hat{x}(k-1) + \alpha x(k) \quad k = 1,2,...,N . \tag{1}$$

$$\hat{y}(k) = (1 - \frac{1}{M})\hat{y}(k+1) + \frac{1}{M}x(k) = (1-\alpha)\hat{y}(k+1) + \alpha x(k) \quad k = N, N-1,...,1 . \tag{2}$$

In the formula above, M is a filter constant. M needs to be bigger than 1 to make the filter stable. α is the gain coefficient of the filter, where $M = 1/\alpha$. k is the time value. Iterate the algorithm and we can get the conclusion that when k is large enough, the impact of the initial value disappear gradually, and even if the initial values are not correct, it will not affect the quality of the final estimation. The Smoothing effect of the bilateral α filter is shown in Fig. 2.

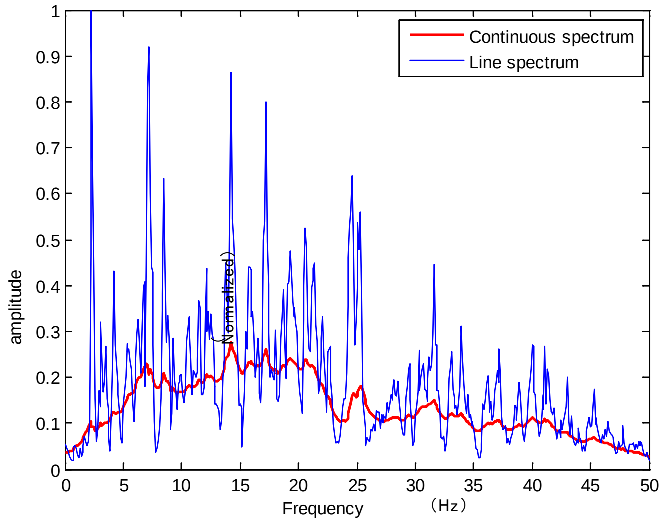


Fig.2 The Continuous Spectrum after The Bilateral α Filter

Line Spectrum Extraction and Extension

Calculate local the maximum sequence of the LOFAR line spectrum and sort all the points by amplitude. After testing large quantities of experiment data, select the appropriate number N_1 of the peaks we need to extract out. The peaks extracted out are shown as Fig. 3.

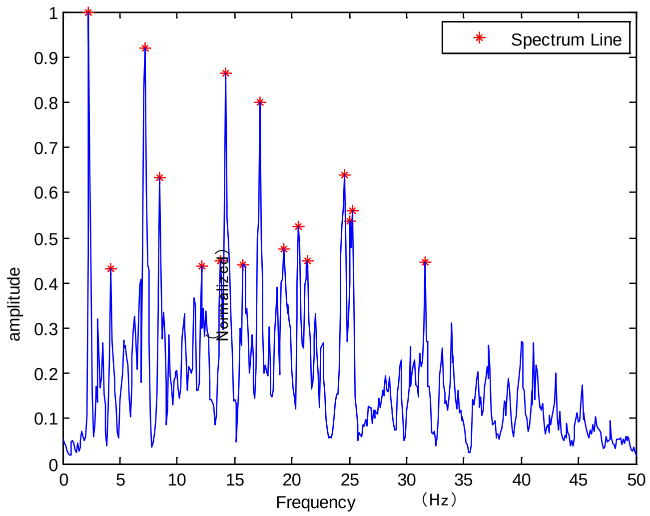


Fig.3 The Peaks Extracted Out

Extend the line spectrum in two essential factors: the peak's frequency and energy. Due to the instability of the receiving signals from different receiving arrays, using the peak amplitude as an energy evaluation is not accurate. Sometimes the peak amplitude decreases, but the width of the peak becomes larger. Therefore, the peak area, the combination of the width of peak and the amplitude of peak, can reflect the peaks' energy more comprehensively. Apply the method above to extend the single frequency points which are already extracted out. Assume that the frequency point to be extended is i, and use H_{iarea} to represent the peak's area. To overcome the effect caused by the offset of the overall line spectrum form different receiving arrays, it needs to widen the single frequency point to a larger range. In this paper, it sets all the points' value in the range $(i-m, i+m)$ to be H_{iarea}. The extended feature of the extracted peaks is illustrated in Fig. 4.

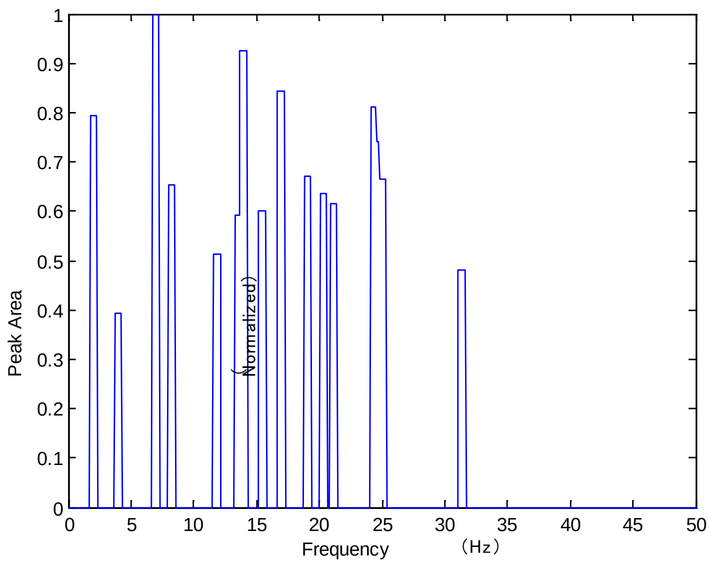


Fig.4 The Extended Feature of The Extracted Peaks

Line Spectrum Comparison

If we extract only N peaks for both LOFAR Spectrums, extend the peaks and compare them, some peaks may be ignored as their amplitude values are unstable, which leads to low similarity score. This paper extracts peaks from the LOFAR Spectrum twice with different peak number and cross contrast the extended feature with each other.

Extract out N_1 peaks from the LOFAR Spectrum by sorted amplitude values and extract out N_2 peaks from the N_1 peaks in the same way, in which $\mathrm{N}_2 < \mathrm{N}_1$ and $\mathrm{N}_2 \approx \mathrm{N}_1 / 2$. Assuming the two LOFAR spectral sequences to be compared are expressed respectively as $a(n)$ and $b(n)$, $n = 1,2,..., N$, then the extracted sequences are $A_{N_1}(n)$, $A_{N_2}(n)$, $B_{N_1}(n)$, $B_{N_2}(n)$, $n = 1,2,..., N$. Compare $A_{N_1}(n)$ with $B_{N_2}(n)$, $A_{N_2}(n)$ with $B_{N_1}(n)$, and $A_{N_2}(n)$ with $B_{N_2}(n)$. As the peaks in $A_{N_1}(n)$ have a larger range, the peaks in $B_{N_2}(n)$ is easier to coincide with the peaks in $A_{N_1}(n)$, and the same situation is in $A_{N_2}(n)$ and $B_{N_1}(n)$. In this way, it improves the stability and anti - interference ability of the comparison.

Similarity formula is defined as follows:

$$\mathrm{S} = \frac{sim(A_{N_1}, B_{N_2}) + sim(A_{N_2}, B_{N_1}) + sim(A_{N_2}, B_{N_2})}{3}, \tag{3}$$

in which, $sim(A_{N_1}, B_{N_2})$ is the similarity function of $A_{N_1}(n)$ and $B_{N_2}(n)$.

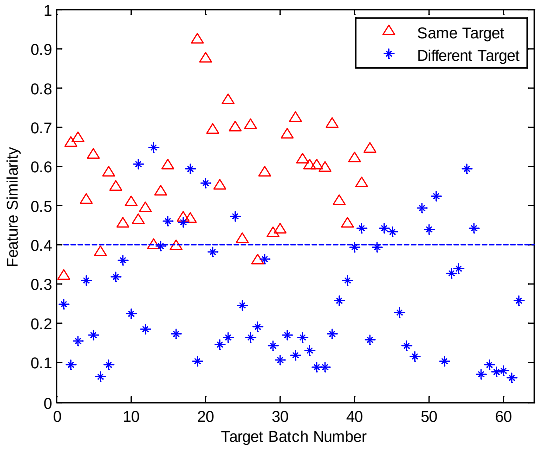
In the numerous methods of similarity calculation, the cosine similarity method performs steadily in calculate the similarity of the characteristic sequence. But the similarity scores are drive down because of the number of peaks extracted out in the two characteristic sequences is different. To solve this problem, the paper gives priority to the sequence with fewer peaks when we calculate the cosine similarity. The specific method is as follows: use $\mathrm{W}_1(n)$, $\mathrm{W}_2(n)$ to indicate whether the frequency point of the sequences $A_{N_1}(n)$ and $B_{N_2}(n)$ has extended line spectrum or not. If the frequency point in $A_{N_1}(n)$ has extended line spectrum, mark the corresponding point in $\mathrm{W}_1(n)$ to be 1, otherwise 0. If the frequency point in $B_{N_2}(n)$ has extended line spectrum, mark the corresponding point in $\mathrm{W}_2(n)$ to be 2, otherwise 0. Add $\mathrm{W}_1(n)$ with $\mathrm{W}_2(n)$ to get $\mathrm{W}_{12}(n)$ and finally set all continuous non-zero frequency points which contain 1 to be 0 and all continuous non-zero points which contain 2 or 3 to be 1. The improved sequence similarity is defined as follows:

$$\mathrm{S} = \frac{sim(A_{N_1} {W_{12}}^{\mathrm{T}}, B_{N_2} {W_{12}}^{\mathrm{T}}) + sim(A_{N_2} {W_{21}}^{\mathrm{T}}, B_{N_1} {W_{21}}^{\mathrm{T}}) + sim(A_{N_2}, B_{N_2})}{3}, \tag{4}$$

in which ${W_{12}}^{\mathrm{T}}$ and ${W_{12}}^{\mathrm{T}}$ indicate the effective extension line spectrum.

Experimental Data Validation

Verify the method in this paper with target signal data which is measured at sea. The target types include merchant ships, fishing boats exploration ships and other multiple types. The experimental data is collected by different receiving arrays and is consist of 42 batches of same target data and 62 batches of different target data. Fig. 5 shows the results of applying single comparison method to all the experimental data. Set the most appropriate threshold and judgment error happens to 18 batches of data. The correct rate is 82.69% in this situation. If we apply the multiple asymmetric comparison to all the data, the result is much better than before, which is show in Fig. 6. After selecting an appropriate threshold, the number of judgment errors reduces to 6 batches of data and the correct rate rises to 94.23%. The new method drives the correct rate up by 14.0%, which indicates the new method is effective.



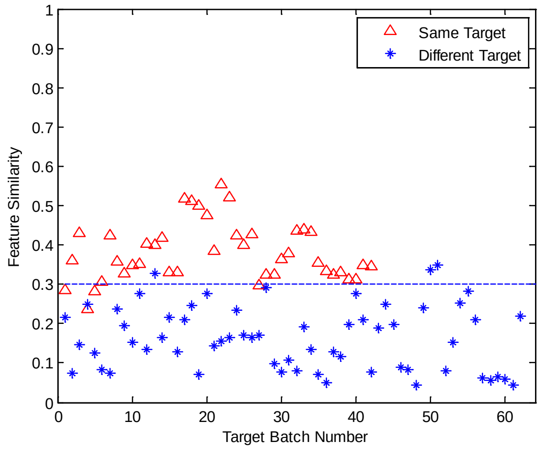


Fig.5 The Single Comparison Method

Fig.6 The Multiple Asymmetric Comparison Method

Summary

The experiment results showed that: the feature based on the peak area of the LOFAR line spectrum can represent the target's feature very well. It takes into account the two essential elements: frequency and energy of the line spectrum peak. The multiple asymmetric comparison method improves the stability and robustness of the comparison, and it is more effective in target similarity judgment.

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