

Conference Proceedings Paper

A Novel Improved Feature Extraction Technique for Ship-radiated Noise Based on Improved Intrinsic Time-scale Decomposition and Multiscale Dispersion Entropy

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Abstract: Entropy feature analysis is an important tool for classification and identification of different types of ships. In order to improve the limitations of traditional feature extraction of ship-radiation noise in complex marine environments, we proposed a novel feature extraction method for ship-radiated noise based on improved intrinsic time-scale decomposition (IITD) and multiscale dispersion entropy (MDE). The proposed feature extraction technique, named IITD-MDE. IITD as an improved algorithm has more reliable performance than intrinsic time-scale decomposition (ITD). Firstly, five types of ship-radiated noise signals are decomposed into a series of intrinsic scale component (ISCs) by IITD. Then, we select the ISC with main information through the correlation analysis, and calculate the MDE value as feature vector. Finally, input the feature vector into the support vector machine (SVM) classifier to analysis and get classification. The experimental results demonstrate that the recognition rate of the proposed technique reaches 86% of accuracy. Therefore, compare with the other feature extraction methods, the proposed method is able to classify the different types of ships effectively.

Keywords: ship-radiated noise; dispersion entropy (DE); multiscale dispersion entropy (MDE); intrinsic time-scale decomposition (ITD); improved intrinsic time-scale decomposition (IITD); intrinsic scale component (ISC); feature extraction

1. Introduction

Ship-radiated noise signal has always been the active research in the field of underwater acoustic signal processing. It contains a lot of information about ship characteristics and is one of the important signs of ship performance [1–4]. In reference [5], the ITD method has obvious advantages in terms of computational efficiency and processing edge effects. However, the definition of the baseline of ITD method [6] is based on linear transformation of the signal itself, it may cause glitch and distortion of the proper rotation components obtained by the decomposition. Based on this, we used the akima interpolation [7] to improve the ITD method, and then the IITD algorithm is proposed. In this paper, IITD is employed for ship-radiated noise signal decomposition to extract effective ISCs from ship-radiated noise signals.

In order to quantify the ship-radiated noise feature information extracted by IITD, we use MDE method. The MDE value indicates the complexity of the signal. In reference [5], FDE methods [8] are single-scale based, they fail to account for the interrelationship of entropy and temporal scales. The coarse-graining process has better stability in feature extraction, it can be combined with arbitrary entropy estimators for multiscale analysis. Regarding this advantage, a multiscale dispersion entropy (MDE) procedure was put forward to estimate the complexity of the original time series over a range of scales [9].

For resolving these problems, we introduces a novel feature extraction technique for ship-radiated noise based on IITD and multiscale dispersion entropy (MDE), named IITD-MDE. The proposed technique not only retains the advantages of existing techniques but also overcomes the disadvantages of ITD and fluctuation-based dispersion entropy (FDE).

2. Results and Discussion

2.1. Theory of IITD

Beacues of ITD method uses a linear transformation method to obtain a baseline signal, it caused the waveform to appear the glitch and distortion. Therefore, in order to overcome this shortcoming, we proposes an IITD method that replaces the linear transformation in the ITD method with akima interpolation. Although akima interpolation is used, it is different from the envelop mean based on local extrema in EMD, because IITD only requires one akima interpolation per decomposition.

2.1.1. Baseline Fitting Method

The comparson of the interpolation method are shown in Figure 1. The proposed method combined with akima interpolation can effectively avoid the overshoot and maintain the advantages of cubic spline interpolation. As the Figure 1(c) shown, this method has a better fitting effect, avoid the phenonmenon of “overshoot”, and has better smoothness.

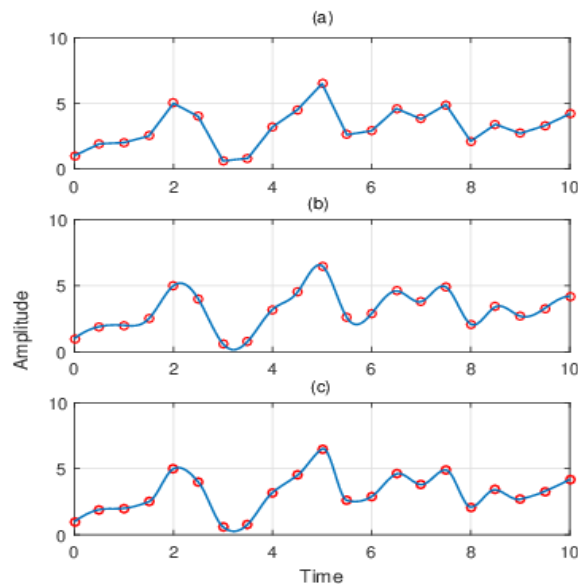


Figure 1. The comparson of the interpolation methods: (a) linear interpolation, (b) cubic spline interpolation and (c) akima interpolation.

2.1.2. Intrinsic Scale Component (ISC)

In the ITD method, PRC of signal decomposition which should satisfy baseline signal control points $L_{k+1} = 0$. Based on this, we defines the ISC of the physical meaning of instantaneous frequency and satisfies the conditions as follows:

- (1) Any two adjacent maxima and minima are monotonic in the whole data segment.
- (2) Let $X_k, k = 1, 2, \dots, M$ denote the extreme points of the whole data segment at time points

$\tau_k, k = 1, 2, \dots, M$, the line connected by any two adjacent maxima points (τ_k, X_k) and minima points (τ_{k+2}, X_{k+2}) , the funtion value of extreme points (τ_k, X_{k+1}) at the corresponding time τ_{k+1} is

$$A_{k+1} = X_k + \left(\frac{\tau_{k+1} - \tau_k}{\tau_{k+2} - \tau_k} \right) (X_{k+2} - X_k) \text{ and its radio to } X_{k+1} \text{ remains the same. These satisfied as}$$

follows: $\alpha \left[X_k + \left(\frac{\tau_{k+1} - \tau_k}{\tau_{k+2} - \tau_k} \right) (X_{k+2} - X_k) \right] + (1 - \alpha) X_{k+1} = 0$ and $\frac{A_2}{X_2} = \dots = \frac{A_6}{X_6} = \dots = \mu$ where $\alpha \in (0, 1)$ is

typical selected as $\alpha = 1/2$. ISC satisfies the conditions are shown in Figure 2.

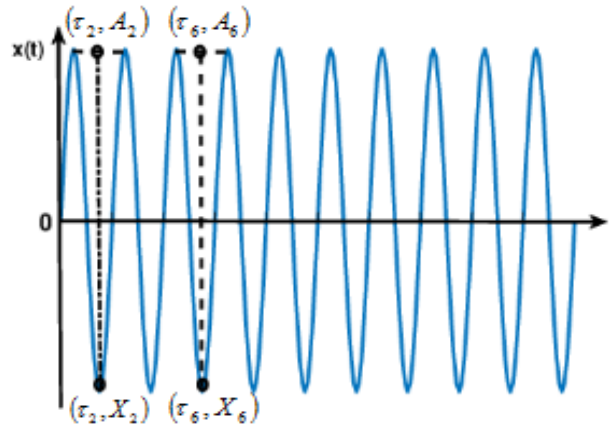


Figure 2. ISC satisfies the conditions.

So, the IITD algorithm can be described as $X_t = \sum_{n=1}^n ISC_n + r_n(t)$, where ISC_n is the n th intrinsic scale component (ISC), $r_n(t)$ is a monotonic trend signal.

2.2. Comparison between ITD and IITD

We apply ITD and IITD to simulation signals. The simulaton signals are separately decomposed by ITD and IITD, and the results of decomposed are shown in Figure 3. As seen in Figure 3, the PRC2 of ITD decomposition has obvious deformation and end effect, and the results of decomposition by IITD method are smoother. In addition, it can be seen from the monotonic trend of signal r that the fitting error of ITD decomposition is also relatively large. Based on the above comparison, the original signal can be decomposed more accurately by using IITD method which benefits from the akima interpolation. At the same time, it can overcome the waveform distortion caused by the ITD method using linear transform to calculate the baseline signal.

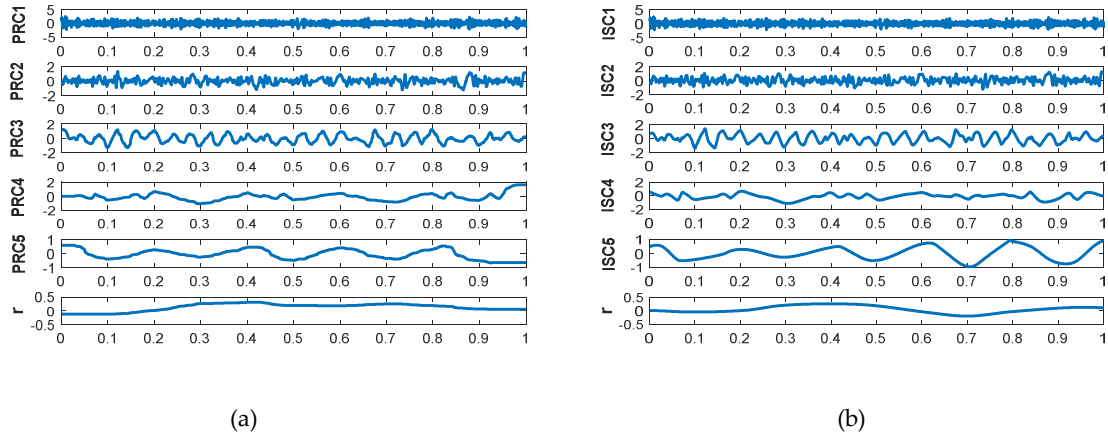


Figure 3. Results of signal obtained by (a) ITD and (b) IITD.

2.3. Theory of Multiscale Dispersion Entropy

In order to overcome the incomplete problem of extracting the complexity of the signal in single-scale, we propose the MDE method. Coarse-grained process has better stability and advantage of feature extraction and error calculation of the signal. Figure 4 shows the coarse-grained process.

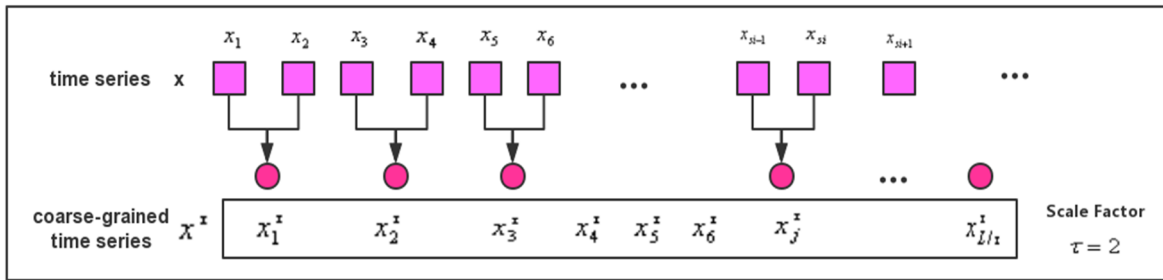


Figure 4. Coarse-grained process.

Under each scale factor, the dispersion entropy of each coarse-grained signal can be calculated by $MDE(x, m, c, d, \tau) = DE(x^{(\tau)}, m, c, d)$.

2.4. Experimental Verification and Analysis

In order to demonstrate the effectiveness of feature extraction method based on IITD and MDE, all data we used are actual ship-radiated noise signals under the same conditions. Five different types of ship-radiated noise signals are selected as sample data, namely ferry ship, cruise ship, passenger ship, submarine and oceanline. For convenience, we respectively name the five ship-radiated noise signals as Ship-A, Ship-B, Ship-C, Ship-D and Ship-E. The sample rate of Ship-A, Ship-B and Ship-D are 44.1 kHz. The sample rate of Ship-C and Ship-E are 52734 Hz. The time domain waveforms are shown in Figure 5.

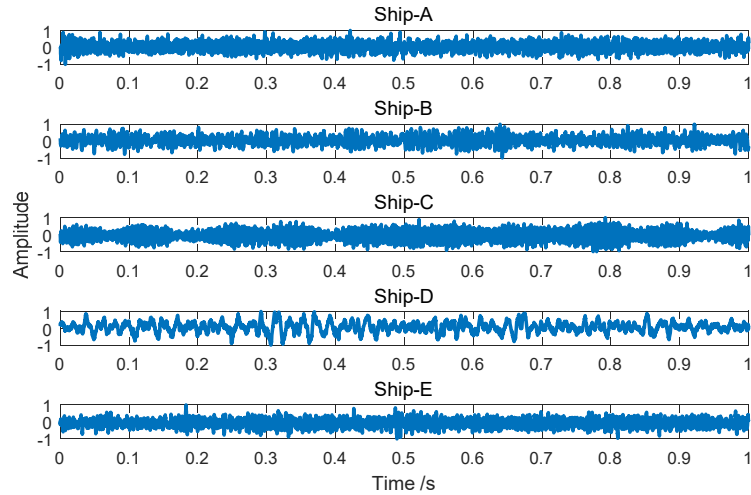


Figure 5. The time-domain waveform of five types of ship-radiated noise signals.

To verify the effectiveness of the proposed feature extraction method, the scale factor of each type of ship-radiated noise signals are selected as 1~20. The IITD-MDE distribution of the five types of ship-radiated noise signals are shown in Figure 6(a), the abscissa represents the scale factor, and the ordinate represents the feature vector MDE. The results demonstrate that the IITD-MDE value is at the same level for the same ships, but there is an obvious difference for different types of ships. The mean and standard deviation of this method are shown in Figure 7(a). The ITD-MDE method results are depicted in Figure 6(b). The means and standard deviations of this method are shown in Figure 7(b). Compared with ITD-MDE method, the experimentals are under the same condition. The results demonstrate the overall entropy values are lower than the proposed method. It can be conclude that the means and standard deviations of the proposed feature extraction method are different, while others are close to each other and the ranges of fluctuations are severely overlapping and non-separable. It indicating that the proposed feature extraction is reliable and better to distinguish ship-radiated noise signals.

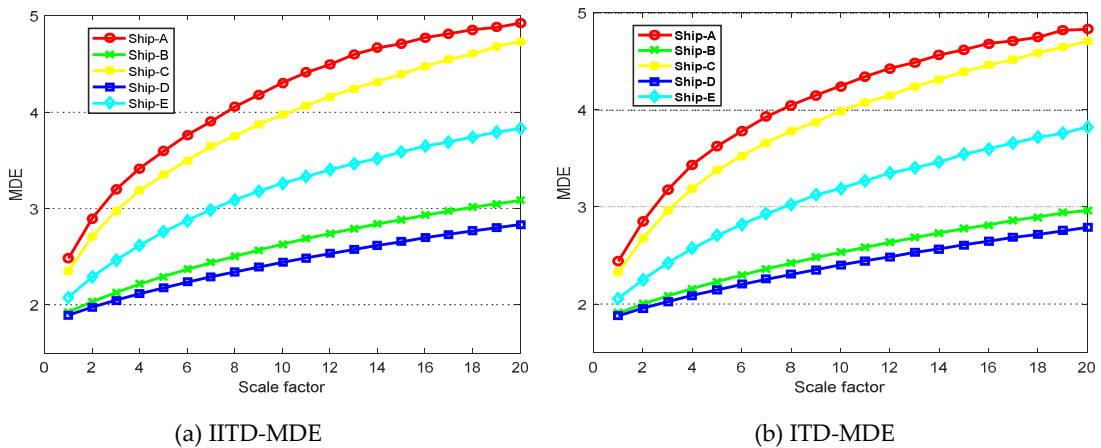


Figure 6. The results of feature extraction method.

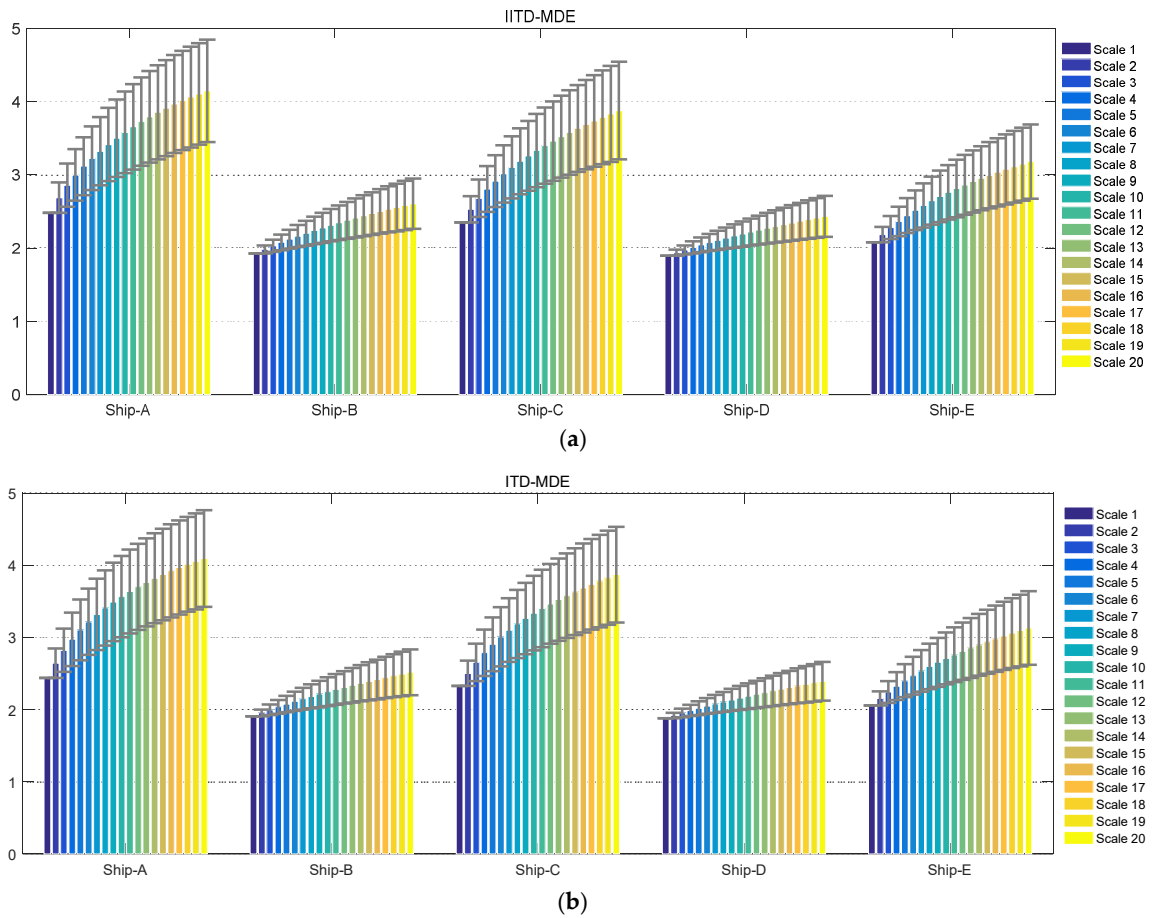


Figure 7. Errorbar graph of these method: (a) IITD-MDE, (b) ITD-MDE.

To implement the automatic identification of ship-radiated noise, the extracted features are inputs of the SVM [10] for training and testing. For each type of ship-radiated noise, 10 samples are used as training set and the remaining 10 samples are used as test set. To compare classification accuracy, the ITD-MDE method is also used to classify ship-radiated noise. The outputs of SVM by using these two methods as feature extractor are shown in Figure 8, and the recognition accuracies are listed in Table 1. Compared with the ITD-MDE methods, the classification accuracy of the proposed method reaches 86%. The results indicate that the proposed method can better classify the five types of ship-radiated noise.

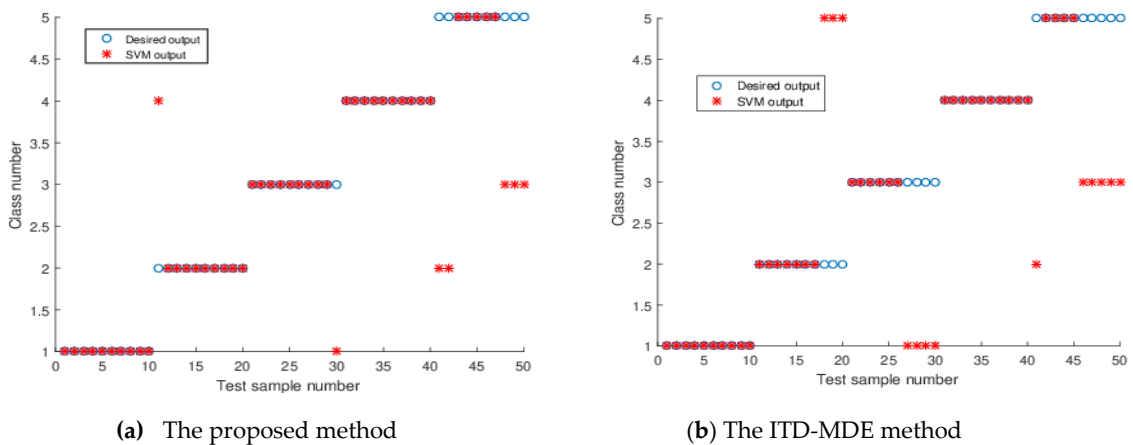


Figure 8. SVM classification results of different methods.

Table 1. SVM classification results of different methods.

Methods	Accuracy Rate
The proposed method	86%
The ITD-MDE method	74%

3. Conclusions

To improve the recognition accuracy of ship-radiated noise signals, a novel feature extraction method based on IITD and MDE is proposed. The main contribution of this paper are highlighted as follows:

- (1) An improved ITD algorithm for ship-radiated noise signal is put forward for the first time in this paper.
- (2) A novel feature extraction algorithm is proposed using IITD and MDE for ship-radiated noise signal in the field of underwater acoustic signal processing.
- (3) We compared with IITD and ITD to simulate and experiments. It is found that IITD overcomes the defect of waveform distortion caused by the ITD method using linear transform to calculate the baseline signal. So , IITD algorithm is better to extract the baseline signal.
- (4) We conduct the simulation experiments to demonstrate that MDE has the advantage of DE, which results in more robust when dealing with noisy signals. Therefore, we applied the MDE method to underwater acoustic signal processing.
- (5) We compare with other extract feature method, IITD-MDE is more precisely and comprehensively to extract the characteristics of ship-radiated noise signal. The classification recognition rate for five types of ship-radiated noise signals is 86%.

Funding: Authors gratefully acknowledge the supported by National Natural Science Foundation of China (No. 11874302, No.11574250 and No.51179157).

Author Contributions: Z.L. designed the project and wrote the manuscript; Y.L., K.Z. and J.G. help to revise the manuscript. All co-authors reviewed and approved the final manuscript.

Conflicts of Interest: The authors declare no conflict of interest.

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