Study of Underwater Target Recognition Using Feature Extraction Based on Wavelet Technology

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Abstract. The characteristic information in target echo’s that using geometry and elastic information is possibly the only way to recognize the underwater target. The findings indicate that if the material of the elastic target is different, the vertical wave velocity and the horizontal wave velocity's relative value is different. Even if the shape is the same, its scattering difference in frequency characteristic is also very obvious, therefore the elastic information may be the only way to recognize the target of the same geometrical shape but material to be different. This paper studies three feature extraction methods based on wavelet technology to obtain the elastic information from the target echo. It can obtain the essential eigenvector and the characteristic dimension is lower than the conventional way. Using the three methods to analyse the target echoes of two different material targets in pond, the recognition ratio shows that the feature extraction method is effective.

1. Introduction

The echo of any complex target is superimposed by the geometric reflection wave determined by the geometric shape of the target and the elastic echo determined by the material of the target. For two underwater targets with similar geometry and different materials, the feature extraction method in time domain seems powerless. How to extract the resonance scattering characteristics, that is, the elastic information of the target, may be the only effective way to distinguish the targets with different materials [1, 2].

Useful information is mostly distributed in one or several frequency bands of underwater target echo spectrum structure. How to extract the information in these frequency bands effectively is very important for underwater target recognition. From the Fourier transform of time-varying signal, we can see that its frequency component is relatively rich, so the energy must expand very wide, and the average energy in the available frequency band is less. This requires a better local method to analyse the echo signal, so as to make the energy of the part of the used signal more concentrated, so as to improve the ability to analyse the target echo signal [3].

Wavelet transform is a time-frequency localization analysis method. Therefore, the feature vectors representing the essence of underwater target can be extracted from the spectrum microstructures of underwater target echoes by using wavelet technology. This method is more comprehensive and sufficient than the conventional simple time-domain or frequency-domain representation. The length of approximation coefficients of wavelet transform decreases by half with the increase of decomposition series, and the number of samples decreases greatly when the last approximation is used as feature vector, so the feature extraction method based on wavelet technology is the key to study.
In view of the above characteristics of the wavelet analysis method, this paper will study the application of three feature extraction methods based on wavelet technology in underwater target recognition: wavelet energy feature, wavelet coefficient amplitude distribution feature and frequency domain discrete wavelet transform feature.

2. Feature Extraction Method Based on Wavelet Technology

2.1. Wavelet Energy Characteristics

For underwater target recognition, the energy spectrum distribution of target echo is closely related to the shape, structure and material of target. It can be affirmed that the energy distribution in scale space after wavelet decomposition is the essential feature of target. Therefore, by comparing the coefficients of each detail signal, the energy characteristics of different targets can be obtained, which can be distinguished into different underwater targets [4].

Specific steps are: the signal is decomposed by multi-level wavelet, and the signal representation in approximation space and detail space is obtained. The signals in approximation space or detail space are transformed by FFT, and the energy of signals in each space is calculated, and they are used as classification features. The advantage of feature extraction is that the dimension of feature is very low, because usually the series of wavelet decomposition will not exceed 10; another advantage is that the feature of signal in different frequency bands is also utilized.

Five-level wavelet decomposition is used to obtain the wavelet coefficients of each scale. The energy of each scale is calculated according to equations (1)-(3) [5].

\[
E_j^d = \frac{1}{E} \sum_{k=1}^{\infty} d_{j,k}^2 \\
E_j^s = \frac{1}{E} \sum_{k=1}^{\infty} s_{j,k}^2
\]

where

\[
E = E_j^i + \sum_{j=1}^{J} E_j^d
\]

In the above equation, \( j \) is the corresponding scale; \( J \) is the scale of wavelet decomposition; \( d_{j,k} \) represents the wavelet coefficients on the \( j \) scale; \( s_{j,k} \) is Wavelet coefficients representing approximate signals.

Figure 1 is the projection of the energy distribution characteristics of the fifth approximation signal and the detail signal in two-dimensional space, using K-L transform. From the graphical point of view, although the feature dimension is very low, it can be completely separated.

![Figure 1. Two dimensional projection chart of wavelet energy.](image-url)
2.2. Distribution Characteristics of Wavelet Coefficient Amplitude

On the one hand, the wavelet coefficients obtained from the wavelet transform of the sampled signal reflect the amplitude distribution of the original signal. On the other hand, it reflects the singularity of the original signal. Therefore, the original signal can be characterized by extracting statistical features of wavelet coefficients in the wavelet transform domain [6].

The extraction process of the amplitude distribution characteristics of the wavelet coefficients can be described as follows: firstly, the underwater target echo signal is transformed by wavelet transform, and the wavelet coefficients on each scale and the approximate signal are calculated; the wavelet coefficients on each scale are normalized; different statistical intervals are selected and the number of times that the wavelet coefficients fall into each statistical interval is counted.

Figure 2 shows the projection of the wavelet coefficients of two different types of underwater target echoes in three-dimensional space using K-L transform. From the three-dimensional projection map, this feature has a certain separability and can be used for target classification.

![Figure 2](image)

**Figure 2.** The 3-dimension projection chart of wavelet coefficient.

2.3. Characteristics of Discrete Wavelet Transform in Frequency Domain

Ref. [7] presents the feature of discrete wavelet transform of signal spectrum, which can eliminate the influence of geometric highlights and extract only the elastic highlights of the target. The specific algorithm is as follows:

Hilbert transform is applied to the target echo, FFT is applied to the analytic signal, FFT is modeled to the result, and discrete wavelet transform is applied to the amplitude-frequency signal of the echo.

After analysis, the fourth approximation coefficients of the discrete wavelet transform of signal amplitude-frequency characteristics mainly contain the elastic characteristics of the target, and the geometric features are filtered out in the detail coefficients. Therefore, the fourth order approximation coefficient (N=15) of discrete wavelet transform (DWT) with signal amplitude-frequency characteristics can be used as target feature to distinguish underwater targets with similar geometric scales from stones (elastic and inelastic targets), but different elastic targets can not be distinguished.

Figure 3 is the 15-dimensional feature of underwater target echo signal extracted by discrete wavelet transform in frequency domain. Figure 4 is the 15-dimensional feature of false target echo signal extracted by discrete wavelet transform in frequency domain. Among them, the ordinate is the normalized value of the feature vector and the abscissa is the vector dimension. Figure 5 shows the projection of two different types of underwater target echo characteristics in three-dimensional space using K-L transform. From the three-dimensional projection map, this feature has a certain separability and can be used for target classification.
Classification experiments were carried out using the extracted three types of features. The classification performances of different eigenvectors under different target states are compared. Among them, the experimental data come from the actual pond experiment. Different feature extraction methods, i.e. wavelet energy feature, wavelet coefficient amplitude distribution feature and frequency domain discrete wavelet transform feature, design the same classifier, which is conducive to the comparison of classification and recognition performance [8].

2.4. Classified Recognition Result of Target Lifting State
Cement column and elastic target are suspended, receiving array is 18 elements. Aiming at the transmitting signals of 0.4ms pulse width, 20 kHz frequency, 25 kHz, 30 kHz, 35 kHz and 40 kHz, the data collected and recorded by primitive 1 is selected for processing, and 18 samples are selected as training samples for each frequency. In this way, 90 training samples are selected [9].

Table 1 gives the classification and recognition results of training samples by different eigenvectors. WT represents the feature of discrete wavelet transform in frequency domain, Energy represents the feature of wavelet energy, and RV represents the feature of amplitude distribution of wavelet coefficients. The following tables all represent this meaning.
Table 1. The recognition ratio (the study swatch).

| Feature Extraction Method | WT  | Energy | RV  |
|---------------------------|-----|--------|-----|
| Number of Correct Recognition Samples | 175 | 123    | 166 |
| Number of Error Recognition Samples    | 5   | 57     | 14  |
| Correct Recognition Rate              | 97.2% | 68.3%  | 92.2% |

At the same time, the data of primitive 2 recorded with training samples were collected as test samples, so that 90 test samples were selected. Table 2 shows the classification and recognition results of different eigenvectors for this kind of test samples.

Table 2. The recognition ratio (the test swatch).

| Feature Extraction Method | WT  | Energy | RV  |
|---------------------------|-----|--------|-----|
| Number of Correct Recognition Samples | 158 | 103    | 170 |
| Number of Error Recognition Samples    | 22  | 73     | 10  |
| Correct Recognition Rate              | 87.8% | 57.2%  | 94.4% |

2.5. Classified Recognition Result of Subsidence State of Target
Cement column and elastic target are in the state of sinking bottom. The selection of training samples and test samples is the same as that of suspension state. Tables 3 and 4 show the classification and recognition results of training samples and test samples with different eigenvectors.

Table 3. The recognition ratio (the study swatch).

| Feature Extraction Method | WT  | Energy | RV  |
|---------------------------|-----|--------|-----|
| Number of Correct Recognition Samples | 180 | 139    | 150 |
| Number of Error Recognition Samples    | 0   | 41     | 30  |
| Correct Recognition Rate              | 100% | 77.2%  | 83.3% |

Table 4. The recognition ratio (the test swatch).

| Feature Extraction Method | WT  | Energy | RV  |
|---------------------------|-----|--------|-----|
| Number of Correct Recognition Samples | 151 | 98     | 107 |
| Number of Error Recognition Samples    | 29  | 82     | 83  |
| Correct Recognition Rate              | 83.9% | 54.4%  | 59.4% |

3. Conclusion
The results of classification and recognition show that:

1. When classifying and identifying the learned samples, the recognition rate is higher, which can reach 80% or more in general, and more than 90% in most cases. It shows that the three feature extraction methods based on wavelet technology selected in this paper are effective.

2. Simply using the same primitive samples collected at the same time as the training samples as the test samples, the classification and recognition effect is not satisfactory. The reasons may be analysed as follows:

   (a) The generalization ability of neural network is not enough. Although the scalability of different neural networks is different, the recognition rate of the learned samples is higher, and the recognition rate of the untrained samples is relatively lower. So far, all the neural network classifiers have the same problem.

   (b) When the target is hoisted, the attitude of the target changes, which results in a great difference in the echo structure of the same target.
(c) In the submerged state, the bottom reverberation becomes the main disturbance, and the target echo is not prominent.
(d) Because of the environment, the elasticity of the target is not very prominent.
(3) Multi-feature fusion recognition will greatly improve the recognition effect.

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