A software realization method of time-frequency feature extraction for underwater target

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Abstract. In response to the demand for feature extraction in underwater target recognition, this article adopts mixed programming technology to design a software implementation method for underwater target time-frequency feature extraction. The time-frequency feature extraction of underwater target radiation noise is achieved through LOFAR and wavelet analysis. The software interface is written using a mixed programming method of MATLAB and C# to build an underwater target time-frequency feature management platform, which can extract, manage, and save time-frequency features, providing a reliable platform for subsequent intelligent recognition of underwater targets.

Keywords: underwater targets; time-frequency feature; feature extraction; mixed programming.

1 Introduction

With the continuous development of technology, our understanding of the ocean is gradually deepening. On the one hand, the development of the marine economy has become an important engine for the development of the national economy[1]: the vast and boundless ocean contains rich mineral resources, marine chemical resources, etc. By improving the ability to explore and develop marine resources, the advantages of marine resources can be transformed into economic advantages, which is of crucial significance for accelerating the speed of economic development. On the other hand, the vast ocean area provides great strategic depth for the military, which also poses a huge challenge to the early warning and defense of marine territories and the protection of marine resources[2]. In economic activities, underwater exploration, monitoring of oil platforms, and detection of economic fish schools all require the identification and detection of underwater targets; In marine defense, the ability to apply underwater acoustic signals to identify and classify underwater targets, accurately determine whether underwater targets belong to ordinary aquatic fish, unknown submarines, or even torpedoes, is crucial for the survival and operation of naval vessels. Therefore, whether it is for the purpose of ocean development economically, or to defend sovereignty, independence, and territorial integrity militarily and politically, it

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is necessary to continuously improve the accuracy and efficiency of identifying targets in water[3][4].

With the tremendous success of convolutional neural network(CNN) in fields such as image detection and speech recognition, some scholars have introduced convolutional neural networks into underwater target recognition[5][6][7]. Convolutional neural networks simulate the visual mechanism of living organisms, and their shared convolutional kernel parameters within hidden layers and sparse connections between layers enable them to learn lattice features (pixels) with small computational complexity, resulting in stable performance and no additional requirements for data. Conducting research on time-frequency feature extraction methods (time-frequency maps) for underwater targets can provide input for convolutional neural networks. The richer the extracted feature information, the more accurate the classification of underwater targets, thereby enabling convolutional neural networks to learn features and achieve excellent recognition of underwater targets. Therefore, this article will focus on addressing the following issues:

1) Research on time-frequency feature extraction algorithms for underwater target radiation noise, providing technical support for underwater target recognition;

2) Determine programming implementation ideas for underwater target feature extraction algorithms and provide implementation approaches for software design;

3) To extract time-frequency features of underwater targets, complete software design and implementation, and provide convenient and fast ways for relevant practitioners to obtain time-frequency features.

2 Research on Time-frequency feature Extraction Algorithm for Underwater Targets

2.1 LOFAR Transformation

The LOFAR(Low-Frequency Array) feature is calculated by performing Short Time Fourier Transform (STFT)[8] on the signal. Unlike traditional Fourier transform which requires signal stationarity, STFT takes advantage of the short-term stationarity of non-stationary signals by windowing and framing the signal before performing Fourier transform to obtain the signal's representation in the time-frequency domain, thus accurately depicting the distribution of signal frequency components and time nodes. The calculation equation is as follows:

$$T_{STFT}\{s(t)\} = \int_{\infty}^{\infty} s(t)w(t-\tau)e^{-jwt}dt \tag{1}$$

Among them, $s(t)$ is the signal to be transformed, and $w(t)$ is the window function (truncation function). The feature extraction steps are as follows:

Step 1: Frame splitting and windowing. Divide the sampling sequence of the signal into K frames, each containing N sampling points. Due to the consideration of correlation between frames, there is usually some overlap in the number of points between the front and back frames. Framing is equivalent to truncating a signal, which can cause distortion in its spectrum and result in spectrum energy leakage. To reduce the impact of spectrum energy leakage, different window functions (Hamming window, rectangular window, Hanning window) can be used to truncate the signal.

Step 2: Normalization and centralization. Normalization and decentralization processing is required for each frame of the signal, as calculated by (2)(3). The purpose of normalization processing is to maintain the amplitude (or variance) of the received signal between 0 and 1; Centralization is to make the mean of the sample zero.

Normalization processing:

$$y_k(n) = \frac{L_k(n)}{\max\limits_{1 \le i \le N}\left[L_k(i)\right]} \tag{2}$$

Centralization processing:

$$x_k(n) = y_k(n) - \frac{1}{N}\sum_{i=1}^{N} y_k(i) \tag{3}$$

Step 3: Perform Fourier transform on signal $x_k(n)$ to obtain the LOFAR spectrum of signal $s(t)$ at frame k. Then, the transformed spectrum is arranged in the time domain to obtain the LOFAR spectrum.

2.2 Wavelet Transform

Wavelet transform[9] uses a time-frequency window that varies with frequency to perform time-frequency analysis on the signal, and gradually performs multi-scale analysis on the signal through scaling and translation operations, ultimately achieving frequency subdivision processing at both high and low frequencies, which can automatically adapt to the requirements of time-frequency signal analysis. Convert the signal $f(t)$ that can be squared and integrated into a continuous wavelet using the following equation:

$$T_{WT}(\alpha, \tau) = \frac{1}{\sqrt{\alpha}} \int_{-\infty}^{+\infty} f(t)\psi\left(\frac{t-\tau}{\alpha}\right) dt \tag{4}$$

In the formula, $WT_x(\alpha, \tau)$ is the wavelet transform coefficient, α is the scaling factor, τ is the translation factor, which are used to adjust the scaling and translation effects on wavelet functions. When the scale factor is large, the wavelet function is stretched, with a larger time-domain width and a smaller corresponding frequency-domain width, and a smaller center frequency, which is used to analyze low-frequency components. When the scale factor is small, the wavelet function is compressed, with a smaller time-domain width corresponding to a larger frequency-domain width and a larger center frequency, which is used for analyze high-frequency components. By adjusting the scaling factor, it is possible to have higher frequency resolution at low frequencies and higher time resolution at high frequencies. Therefore, continuous wavelet transform is a multi-resolution time-frequency analysis that can obtain a more detailed representation of the joint distribution of time and frequency.

Convert the collected radiated noise into a wavelet time-frequency map, and the specific implementation process is as follows:

If α is the scale, f_s is the sampling frequency, and F_c is the wavelet center frequency, then the actual frequency F_a corresponding to α is:

$$F_a = F_c \cdot f_s / \alpha \tag{5}$$

The scale sequence form is:

$$k / Lscale, k / (Lscale - 1), \cdots, k / 2, k \tag{6}$$

In the formula: $Lscale$ is the length of the scale sequence used to perform wavelet transform on the signal; k is a constant; The actual frequency corresponding to scale $c / Lscale$ is $f_s / 2$. Therefore, according to (6), the scale sequence can be obtained:

$$k = 2 \times F_c \times Lscal \tag{7}$$

Based on the determined wavelet basis and scale, calculate the wavelet coefficients using (4); Then, according to (5), convert the scale sequence into an actual frequency sequence; Finally, by combining the time series, a wavelet time-frequency map can be drawn to obtain feature information.

2.3 Discussion and Analysis

Time frequency analysis aims to have both high time resolution and frequency resolution, with strong real-time frequency localization ability. But in fact, time localization and frequency localization are contradictory. If the window function has a narrow distribution in the time domain, then it has a wider distribution in the frequency domain and cannot make the distribution widths in both the time and frequency domains arbitrarily small at the same time. In time-frequency analysis, higher frequency resolution should be pursued for low-frequency components and higher time resolution for high-frequency components. When a window function is given, the time domain width and frequency domain width are also determined accordingly. Therefore, the Short Time Fourier Transform is a single resolution time-frequency analysis that can only meet one aspect of the requirements in terms of time resolution and frequency resolution, and cannot overcome the contradiction of time-frequency localization. By comparison, continuous wavelet transform can adaptively adjust the time-frequency localization characteristics. However, LOFAR spectrograms still have important application value in extracting line spectrum features and determining narrowband components of sound sources.

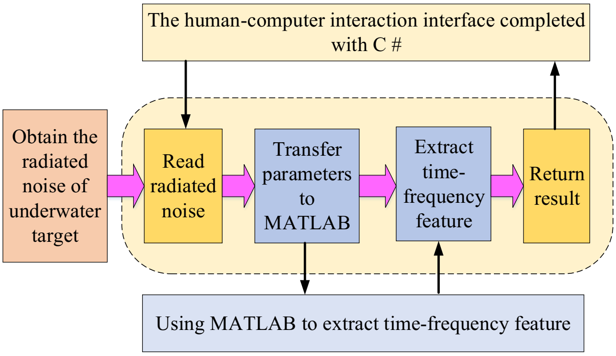

Fig. 1. Implementation process of mixed programming for time-frequency feature extraction

3 Implementation of Mixed Programming for Time-Frequency Feature Acquisition

MATLAB is a powerful, efficient, and highly interactive high-level computer language that integrates functions such as numerical calculation, signal processing, and graphic analysis. But at the same time, it also has disadvantages such as poor interface development ability, and the disclosure of source code is not conducive to the confidentiality of algorithms and data. And C# is a new type of object-oriented high-level programming language. The system developed with C# has the advantages of user-friendly interface, fast execution speed, easy maintenance and upgrading, and can generate executable files, effectively protecting algorithms and data. However, compared to MATLAB programming, C# programming is more complex, especially in complex computational programming. Therefore, this article will be based on C# and MATLAB mixed programming to achieve the design of time-frequency feature extraction software[10].

The mixed programming process for time-frequency feature extraction is shown in Fig. 1. The main steps to achieve time-frequency feature extraction include obtaining underwater target radiation noise, reading radiation noise data in human-computer interaction software, transmitting parameters to MATLAB, performing time-frequency feature extraction operations in the MATLAB engine, and MATLAB returning the extraction results to the software. The specific process is:

1) Generate a .dll file. After implementing the time-frequency feature extraction algorithm in MATLAB, it is encapsulated into a function statement. Then type "deploytool" in the MATLAB command window, select "Library Compiler" in the pop-up window, enter the compiler, and select "NET Assembly" and feature extraction functions, name the class name and namespace, and finally perform "Package" compilation, waiting for the generation of the .dll file.

2) Add a .dll component reference: Add the .dll file generated by step 1) and the MATLAB library file "MWArry.dll" to the "Reference" of the Visual studio 2015 solution.

3) Add a reference to the. m file in the program (using the "using+namespace name" statement), and also add the reference: "using MATLAB NET.Arrays".

4) Write the code. In the corresponding function module, the code of the method with the same name of the.m file can be realized by using MATLAB functions to calculate, and can receive the data value returned by the function.

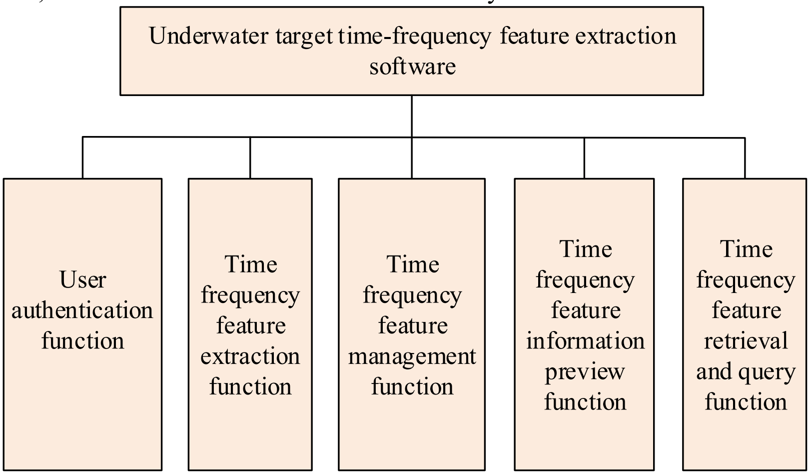

Fig. 2. Software functional module

4 Design and Implementation of Underwater Target Time Frequency Feature Extraction Software

4.1 Development Environment

The human-computer interaction interface is programmed using C# language in the Visual Studio 2015 development environment, and some controls in the interface use the SeeSharpTools software component of Jianyi Technology's Ruishi Measurement and Control Platform. The time-frequency feature extraction algorithm for underwater target radiation noise is implemented using MATLAB language programming, and the programming software is MATLAB 2019b.

4.2 Requirements Analysis

The underwater target time-frequency feature extraction software needs to support users in obtaining time-frequency features (calculating the time-frequency analysis results based on the radiated noise of underwater targets), importing and exporting time-frequency features, entering, modifying, and deleting relevant information, querying and retrieving time-frequency features, and previewing time-frequency feature maps. Therefore, the functions that underwater target time-frequency feature extraction software needs to have are:

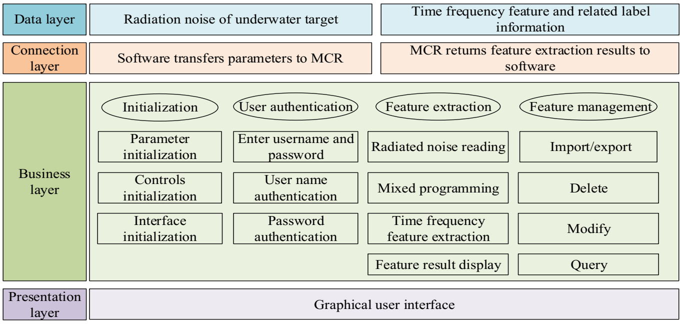

Fig. 3. Architecture design of softwar

Fig. 4. Software login interface

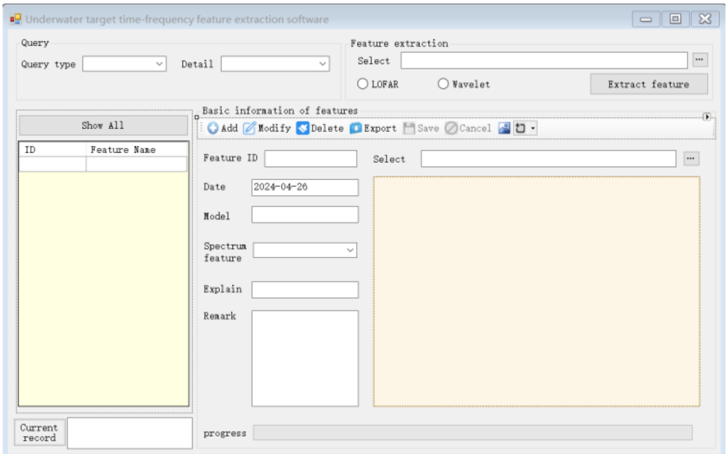

Fig. 5. Main operation interface

User Authentication Function.

The software can identify the user who logs into the system, and the user needs to enter the correct username and password before using the software.

Time Frequency Feature Extraction Function.

The software conducts time-frequency analysis on the radiated noise signal of underwater targets, and uses the time-frequency feature extraction method in Section 2 to calculate the LOFAR time-frequency map of the signal.

Time Frequency Feature Management Function.

The software can complete the import and export of time-frequency charts, input, modify, and delete relevant label information of time-frequency charts, facilitating the management of time-frequency data and helping users fully utilize time-frequency information.

Time Frequency Feature Information Preview Function.

The software can preview the information of the stored time-frequency chart and display the relevant information entered.

Time Frequency Feature Retrieval and Query Function.

The software can retrieve and query time-frequency maps based on the information labels of the time-frequency map input (such as the name of the time-frequency map, corresponding underwater targets, underwater target radiation noise, spectrum situation, data description, upload date, etc.).

Each function does not exist independently. While completing their own tasks, they also participate in the completion of other functional tasks. They are interdependent and cooperate with each other. The functional module of the underwater target time-frequency feature extraction software is shown in Fig. 2.

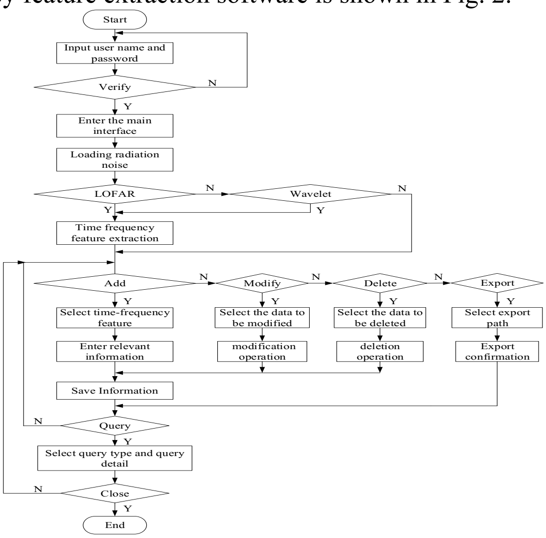

Fig. 6. Software flowchart

4.3 Software Design

According to the requirement analysis of underwater target time-frequency feature extraction software, the software adopts a layered architecture, which is divided into four layers: data layer, connection layer, business layer, and presentation layer. As shown in Fig. 3.

Data Layer.

The software architecture is based on the data layer. The data layer includes underwater target radiation noise signals, time-frequency characteristics, and related label information, and the implementation of each function revolves around the data layer.

Connection Layer.

The software connection layer utilizes a mixed programming technique of MATLAB and C# to achieve parameter transfer and result return between the software and the MATLAB engine environment (MCR, matlab compiler runtime).

Business Layer.

The business layer of software, namely the software logic functional module, includes four contents:

The initialization module mainly.

The initialization module mainly functions to complete parameter initialization, control initialization, and underwater target time-frequency feature extraction software system initialization.

The user authentication module.

The user authentication module mainly functions as username and password input, username authentication, and password authentication. For those whose usernames and passwords do not meet the requirements or do not have permission to log in to the system or perform related operations, this is to ensure the security of time-frequency feature data and related label information of underwater targets.

The time-frequency feature extraction module.

The function of the module is to read the radiated noise, calculate and analyze time-frequency maps, and display time-frequency result. In this module, time-frequency feature extraction is achieved through mixed programming techniques of C# and MATLAB. Taking the extraction of LOFAR feature as an example, the implementation process is explained: first, write the time-frequency feature extraction function "getLOFAR.m" in MATLAB, and compile it into a .dll file that can be called by C#; Add the corresponding namespace using the statement "using myDLLgetLOFAR;" in C#, and also add "myDLLgetLOFAR.dll" in "Reference"; Finally, in the program, use "ClassgetLOFAR lofar=new ClassgetLOFAR(); lofar. getLOFAR (1, input1, input2, input3, input4,……)".

The time-frequency feature management module.

The main function of the time-frequency feature management module is to import/export time-frequency feature maps, delete time-frequency feature maps, modify time-frequency feature maps, and query time-frequency feature maps. This module can meet the basic requirements of users for storing time-frequency features.

Presentation layer.

The presentation layer of software is the graphical user interface. In this user interface, users can complete operations such as time-frequency feature acquisition and time-frequency feature storage management through the operation buttons on the interface, which has good human-computer interaction performance.

4.4 Software Implementation

The software development environment and graphical interface design development framework is .NET framework4.5. The programming language is C#, and the software is used in the Windows operating system. The underwater target time-frequency feature extraction software has an intuitive user interaction interface. Open the software, after initialization is completed, enter the software login interface shown in Fig. 4. After successfully verifying the username and password, enter the main operation interface as shown in Fig. 5.

The main loop flowchart of the underwater target time-frequency feature extraction software is shown in Fig. 6.

5 Conclusions

The implementation of underwater target time-frequency feature extraction software adapts to the current development needs of underwater target recognition technology. This article adopts hybrid programming technology, and completes the design and implementation of the software through requirement analysis, functional modular design, and software architecture design. The software can extract time-frequency features of underwater target radiation noise, manage and save time-frequency feature maps.

In addition, with the development of various underwater target vibration and noise reduction technologies, the stealth level of underwater targets will be increasingly high. Therefore, higher requirements are put forward for feature extraction technology. The following two points are worth further consideration and research:

- Research on feature extraction methods for underwater target radiation noise, in addition to time-frequency domain features, explore feature extraction methods in multiple dimensions such as time-domain and frequency-domain, in order to solve the problem of unclear spectral features caused by vibration reduction and noise reduction technology, which makes underwater targets difficult to recognize.

- Realizing real-time extraction of time-frequency characteristics of underwater target radiation noise, with the development of informationization and digitization of underwater targets, underwater target recognition systems will inevitably move towards intelligence and informationization, which puts higher requirements for real-time and accuracy in extracting time-frequency characteristics of underwater target radiation noise.

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