Time-Frequency Analysis and Identification method for weak Magnetic signal of Submarine in aeromagnetic Detection

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Abstract. As an important strategic weapon, submarine detection is very difficult. Aeromagnetic detection is one of the main detection methods, but there are some problems such as complex measurement environment and difficult recognition of target magnetic signals. To solve this problem, wavelet threshold denoising is used to suppress magnetic noise, and WVD is used to analyze the magnetic signal in time and frequency to improve the recognition ability of the unexploding target magnetic signal. The simulation results show that this method is feasible.

1. Introduction
The submarine has good concealment and strong threat, and it is valued by the navies of all countries. With the development of weapon and equipment technology, the submarine's combat capability is increasing, and the anti-submarine task is becoming more arduous, and the requirements for various anti-submarine methods are becoming higher and higher. Compared with other methods of submarine exploration, aeromagnetic exploration has the advantages of fast response, simple use and high reliability, and has been widely used in some military powers[1].

Among the many detection methods, magnetic detection is a method to measure magnetic anomalies produced by underground or underwater magnetic objects and corresponding data processing and interpretation methods, which is widely used in geophysical investigation. Solid mineral exploration, underwater sunken ship or submarine detection and underground nuclear explosive inspection are also one of the most commonly used methods for detecting underground unexploded targets. If there is a large amount of ferromagnetic material in the complex detection site in the medium environment, it is difficult to eliminate the interference of other ferromagnetic materials by using the traditional data processing method, resulting in high false alarm rate and even unable to judge the location of the unexploded target[2]. Orthogonal basis decomposition can improve the signal-to-noise ratio of target signal, but it is usually used to detect large targets such as submarines.

In order to solve the problem that it is difficult to identify the magnetic signal of the target in the course of aeromagnetic detection, the wavelet threshold denoising method is used to suppress the magnetic noise, and the wigner-ville distribution method is used for time-frequency analysis to identify the target signal. It can greatly improve the recognition ability of target magnetic signal.

2. The magnetic signal of Submarine Ordnance
The space magnetic field distribution of the undetonated target is simulated, and the target magnetic signal in aeromagnetic detection is obtained. In aeromagnetic detection, two dimensions are generally used for target detection to determine the target plane position, as shown in figure 1. In the course of
aeromagnetic detection, UAV will measure the magnetic signal of the target through the positive distance of the target. The orthogonal detection coordinate system is established. The UAV first detects along the x axis to determine the x axis coordinates of the unexploded targets, then detects along the y axis direction to determine the y axis coordinates of the unexploded targets, and finally determines the plane coordinates of the targets.

![Fig. 1. Roadmap of Aeromagnetic Survey](image)

When the distance between the detection platform and the magnetic target is far greater than 2.5 times the length of the target, the magnetic target can be replaced by the magnetic dipole model. In practical engineering application, the relative distance between the unmanned aerial vehicle and the unexploded target is far longer than that of the unexploded target. At this point, the unexploded target can be replaced by a magnetic dipole. The magnetic target is described by six unknowns, that is, $M(M_x,M_y,M_z)$, the 3D magnetic moment and its 3D position on the x axis, y axis and z axis. In the detection of the magnetic target, the magnetic target detection system is first modeled. The magnetic target is regarded as stationary, the UAV flies at a certain speed, the magnetic target is set as the origin, and the space position coordinate of the UAV is set as the origin $(x, y, z)$. The magnetic field generated by the magnetic target at the location of the detection platform is:

$$B = \frac{\mu}{4\pi r} \times \left[ \frac{\mathbf{M} \times \mathbf{r}}{r^3} - \mathbf{M} \right] \quad (1)$$

The total magnetic field generated by the above undetonated target at the UAV position belongs to the vector magnetic field, which can be decomposed into three orthogonal axis magnetic fields $B_x$, $B_y$, $B_z$, in the form of vector sum, coupled with the three-dimensional magnetic moment of the target. The 3D magnetic field of the magnetic target can be directly determined by the 3D magnetic moment of the target and the relative position between the target and the UAV. The magnetic field generated by the magnet target at the location of the detection platform is further decomposed into the form of a magnetic field along the axis, the three-dimensional direction of the axis $x$, $y$, $z$. The 3D magnetic field generated by the magnetic target in the UAV can be represented by the 3D magnetic moment of the magnetic target and the relative position between the target and the UAV:

$$\begin{bmatrix} B_x \\ B_y \\ B_z \end{bmatrix} = \frac{\mu}{4\pi r^3} \times \begin{bmatrix} 3x^2 - r^2 \\ 3xy \\ 3xz \end{bmatrix} \begin{bmatrix} M_x \\ M_y \\ M_z \end{bmatrix} \quad (2)$$

Among them, $B_x$, $B_y$, $B_z$ is the component of the total magnetic field produced by the magnetic target in the direction of axis $x$, $y$, $z$ at the UAV. $\mu$ is the permeability of medium. $r$ is the relative distance between the detection platform and the magnetic target. The formula (2) shows that the three-dimensional magnetic field of the magnetic target depends on the magnetic
moment of the magnetic target, the distance between the magnetic target and the detection platform, and the position coordinates of the magnetic target.

![Image of magnetic target and geomagnetic field relationship](image)

**Fig. 2.** Relationship between magnetic field of undetonated target and geomagnetic field.

Figure 2 shows the relationship between the magnetic field generated by the unexploded target at the detection platform and the geomagnetic field. The magnetic field produced by submarine is $\vec{B}$, and the geomagnetic field produced by UAV is $\vec{B}_E$. The geomagnetic field can be considered to be uniformly distributed in a narrow range. The total magnetic field measured by the unmanned detection platform is $\vec{B}_S$. It is synthesized by the constant geomagnetic field part ($\vec{B}_E$) and the anomalous magnetic field generated by the magnetic target at the detection platform.

$$\vec{B}_S = \vec{B}_E + \vec{B}$$  \hspace{1cm} (3)

The analysis shows that:

$$S = |\vec{B}_S| - |\vec{B}_E| \approx \vec{B} \cdot \vec{B}_E / |\vec{B}_E|$$  \hspace{1cm} (4)

$e_i$ is the unit vector in the direction of the geomagnetic field. Formula (4) shows that the magnetic anomaly signal of the unexploded target at the unmanned platform is the projection of the magnetic anomaly field produced by the magnetic target at the unmanned platform in the direction of the geomagnetic field$^{[6]}$.

![Image of spatial magnetic field distribution](image)

**Fig. 3** Spatial magnetic field distribution of undetonated target

The spatial magnetic field distribution of the target can be obtained by simulation. Fig. 3 shows the magnetic field distribution of a typical unexploded target. By setting different detection routes, various magnetic signals of unexploded targets can be obtained. As shown in Figure 4, four typical magnetic signals of unexploded targets can be obtained.

![Images of typical magnetic signals](image)

**Fig. 4** Typical magnetic signal of undetonated target
3. Noise reduction of Target Magnetic signal

Aeromagnetic signal has magnetic noise. By denoising, the noise can be further eliminated and the time domain recognition ability of target signal characteristics can be improved. In order to further enhance the signal-to-noise ratio of aeromagnetic measurement signal, the method of wavelet threshold denoising is used to denoise the measurement signal. In the coefficients of each layer of wavelet decomposition, the coefficients whose modulus is greater than or less than a certain threshold are processed separately, and then the processed wavelet coefficients are reconstructed.

The commonly used threshold functions are divided into hard threshold function and soft threshold function. Hard threshold is to set the wavelet coefficients whose absolute value is less than the threshold value to 0, which can well preserve the local features such as signal edge, but the signal will be distorted as a whole. Soft threshold is to set the wavelet coefficients whose absolute value is less than the threshold value to 0, at the same time, to compress the remaining non-zero coefficients to 0, the soft threshold processing is relatively smooth, but it may cause local loss such as signal edge blurring. True phenomenon. Then the signal is reconstructed according to the coefficients selected by the threshold, and the denoised signal is established.

When the high frequency part of the signal is very small in the noise domain, unbiased likelihood estimation threshold and minimax criterion threshold can only remove less magnetic field noise, and the heuristic threshold can more effectively remove magnetic field noise.

![Schematic diagram of wavelet analysis](image)

**Fig. 5** Schematic diagram of wavelet analysis

The sym8 wavelet five-layer wavelet decomposition is selected and the wavelet coefficient threshold is quantized by using the heursure soft threshold. After wavelet denoising, the target magnetic signal shown in figure 6 is obtained.

![Signal schematic diagram after wavelet denoising processing](image)

**Fig. 6** The signal schematic diagram after wavelet denoising processing

The signal-to-noise ratio of B1 magnetic signal, B2 magnetic signal, B3 magnetic signal and B4 magnetic signal are increased by 11.3 db., 10.5db, 12.1dband 11.1 db. after wavelet de-noising.

4. Time-Frequency Analysis and Identification of Target Magnetic signal

The magnetic signal of the undetonated target is a non-stationary signal. The statistical characteristics change with time in view of the non-stationary signal or time-varying signal. The time-frequency analysis method is generally used to analyze and process the magnetic signal. Time-frequency analysis combined with time-domain and frequency-domain characteristic analysis of non-stationary signals...
reflects both the frequency of the signal and the variation of the frequency with time, which further improves the signal-to-noise ratio of the signal and enhances the ability of target recognition.

In time-frequency analysis, if the length of window is too long, the assumption of stationarity is not easy to hold, and the resolution in time domain becomes worse, otherwise, the resolution of frequency becomes worse if the length of window is too short. In order to solve this problem, a bilinear transformation of connection time and frequency is needed to map one-dimensional time-function or frequency-function to a two-dimensional function of time-frequency. And it can accurately reflect the distribution of signal energy with time and frequency. Therefore, wigner-ville time-frequency distribution (WVD) is used to analyze and process the magnetic signal of the target.

If a continuous time signal is set, the wvd of the signal is:

\[ W_s(t, w) = \int_{-\infty}^{\infty} x(t + \frac{\tau}{2})^* x(t - \frac{\tau}{2}) e^{-j\omega \tau} d\tau \quad (5) \]

The wvd transform of discrete time signal is obtained after discretization of continuous time signal.

\[ W_s(n, w) = 2 \sum_{k=-\infty}^{\infty} x(n + \frac{k'}{2})^* x(n - \frac{k'}{2}) e^{-j\omega k'} \quad (6) \]

WVD satisfies many expected mathematical properties and is not constrained by window function, so it can accurately locate the time-frequency structure of the signal. If the energy of the signal is concentrated in the \((t_0, f_0)\), the energy of the signal wvd is also concentrated in the \((t_0, f_0)\). If the time-domain support set of signal \(x(t)\) is \((t_0 - \Delta t, t_0 + \Delta t)\), then the time-domain support set of the WVD signal is \((t_0 - \Delta t, t_0 + \Delta t)\). If the frequency domain support set of signal \(x(t)\) is \((f_0 - \Delta f, f_0 + \Delta f)\), then the frequency domain support set of the signal WVD is also \((f_0 - \Delta f, f_0 + \Delta f)\).

The time and frequency of the signal are well positioned by wvd. The time-frequency distribution of the magnetic signal of the target is obtained by using the wvd transform method.

\[ \text{Fig. 7 Target magnetic signal WVD analysis diagram} \]

After processing the magnetic signal of the unexploded target by wvd, we can see that the signal-to-noise ratio of the magnetic signal of the target is further improved. As shown in figure 7, the four magnetic signals are all low-frequency signals, and the location of the magnetic signals of the target is very bright, and the target signal can be recognized.

5. Summary
Detection of submarines has urgent practical significance and high difficulty. In this paper, wavelet threshold de-noising is used to suppress magnetic noise, and WVD is used to analyze magnetic signals in time and frequency to improve the signal-to-noise ratio of magnetic signals of unexploded targets and enhance the recognition ability of magnetic signals of targets. The preliminary simulation results show that this method of time-frequency analysis and recognition of magnetic signals can achieve better recognition results.
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