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Wavelet-based Adaptive Enhancement Method of Aeromagnetic Anomaly Signal

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ABSTRACT: In view of the wide and effective application of wavelet transform in the study of weak signal detection, it has been applied to the enhancement of magnetic anomaly signal of underwater target. But there is a problem of the decomposition level selection in the process of wavelet enhancement , which is related to the parameters of Aeronautical platform and underwater target. In this paper, based on the detection model of underwater target magnetic field, the selection model of wavelet decomposition level of aeromagnetic anomaly signal was established, and was realized adaptive wavelet enhancement of aeromagnetic anomaly signal by weighted reconstruction. The processing results of the simulation test signal show that the method can effectively enhance the weak magnetic signal of underwater target.

1. Instruction

The detection of magnetic anomaly signal of underwater target by airborne platforms equipped with high-sensitivity magnetic detectors has become an important means of aerial anti-submarine detection operations. But in the actual detection process, the signal-to-noise ratio of magnetic anomaly signal is usually less than 1 due to the influence of geomagnetic background, and the types of these noise include white Gaussian noise, non-Gaussian noise and colored noise. These complex noises greatly increase the difficulty of detecting the magnetic anomaly signal of underwater target[1-5].

In view of the wide and effective application of wavelet transform in the field of weak signal detection, it has been applied to the enhancement of magnetic anomaly signal of underwater target[6-7]. The magnetic anomaly signal of underwater target exists in several decomposition level after discrete wavelet transform. Weighted reconstruction of these decomposition level can effectively enhance the magnetic anomaly signal. But there is a problem of choosing the decomposition level in the process of wavelet enhancement , which is related to the parameters of Aeronautical platform and underwater target. In this paper, based on underwater target magnetic detection model, the calculation formula of signal characteristic time width was deduced, and the signal characteristic frequency range was estimated by simulation, and the selection model of wavelet decomposition level of aeromagnetic anomaly signal by was established, which realized adaptive wavelet enhancement of aeromagnetic anomaly signal. The processing results of the simulation test signal show that the method can effectively enhance the weak magnetic signal of underwater target.

2. The detection model of underwater target magnetic field

When the detection distance is more than 2.5 times the length of the magnetic target, the magnetic target can be regarded as a magnetic dipole [8]. Under these conditions, the magnetic field at the distance $\boldsymbol{r}(x, y, z)$ from the magnetic target can be expressed as[9-10].

$$\boldsymbol{B}=\frac{\mu_0}{4\pi}\left[\frac{3(\boldsymbol{m}\cdot\boldsymbol{r})\boldsymbol{r}}{r^5}-\frac{\boldsymbol{m}}{r^3}\right] \tag{1}$$

Formula (1) is mathematical model of magnetic dipole. $\boldsymbol{m}(m_x,m_y,m_z)$ is magnetic moment of magnetic target; μ_0 is permeability of vacuum; $r=|\boldsymbol{r}|$ is the distance from magnetic target to measuring point.

After vector operation of the magnetic dipole model (1), we can get the following formula.

$$\begin{bmatrix}B_x\\B_y\\B_z\end{bmatrix}=\frac{\mu}{4\pi r^5}\begin{bmatrix}3x^2-r^2 & 3xy & 3xz\\3xy & 3y^2-r^2 & 3yz\\3xz & 3yz & 3z^2-r^2\end{bmatrix}\begin{bmatrix}m_x\\m_y\\m_z\end{bmatrix} \tag{2}$$

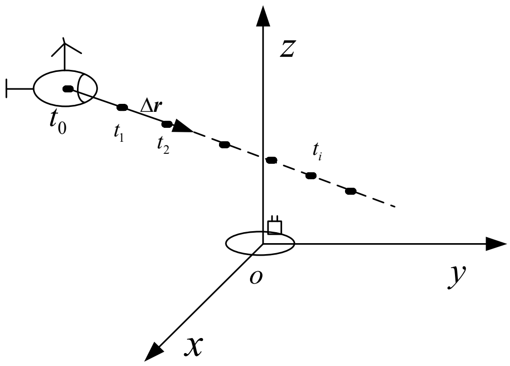

Figure 1 The aeromagnetic detecting diagram of underwater target field

The aeromagnetic detecting diagram is shown in the figure 1. The relative velocity of the aeronautical detection platform is $\boldsymbol{v}$, and the measurement accuracy of the magnetometer is σ .

The maximum detection distance of magnetometer under the accuracy σ is defined as the characteristic space length L_t . According to the magnetic dipole model (1), the expression of the characteristic space length L_t is deduced as formula (3).

$$L_t=\sqrt[3]{\frac{\mu|\boldsymbol{m}|}{2\pi\sigma}} \tag{3}$$

The longest time of magnetic anomaly signal recorded by magnetometer is defined as the characteristic time width T_t , According to formula (1), the expression of the characteristic time width T_t is deduced as formula (4).

$$T_t=\frac{2L_t}{|\boldsymbol{v}|} \tag{4}$$

3. the selection model of wavelet decomposition level

3.1 Frequency analysis of magnetic anomaly signal

Based on the detection model of underwater target magnetic field, multiple typical magnetic anomaly signals can be emulated, and the frequency band of these signals can be calculated and shown as figure 2, when the characteristic time width T_t is 1.

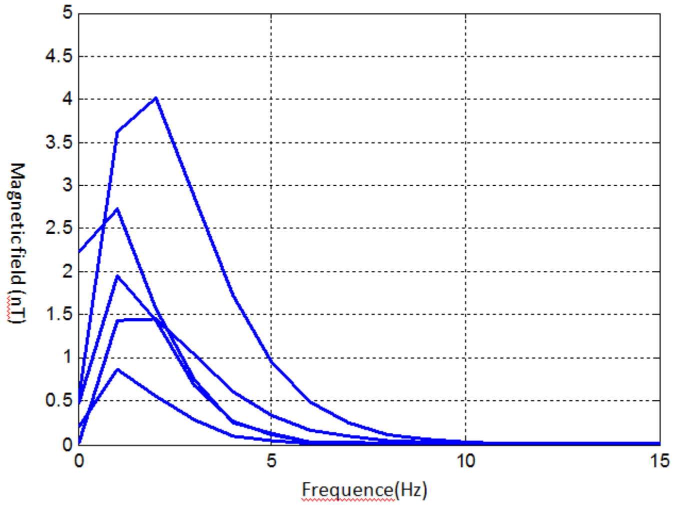

Figure 2 Frequency band of multiple typical magnetic anomaly signals

Analyzing the frequency band of multiple typical magnetic anomaly signals, we can get the calculation formula (5), which is the frequency band of underwater target aeromagnetic anomaly signal.

$$\begin{cases} f_{low} = \dfrac{1}{T_t} \\ f_{high} = \dfrac{10}{T_t} \end{cases} \tag{5}$$

3.2 the calculation of wavelet decomposition level selection

The wavelet basis function which is the closest to the underwater target magnetic signal is selected, and the original signal is decomposed into wavelet coefficients and scaling coefficients of different level. The multi-resolution decomposition formula is as follows.

$$\begin{cases} c_{m+1}(k) = \sum\limits_{n=-\infty}^{\infty} h_0^*(n-2k)c_m(n) \\ d_{m+1}(k) = \sum\limits_{n=-\infty}^{\infty} h_1^*(n-2k)c_m(n) \end{cases} \tag{6}$$

In formula(6), $h_0(k) = \langle \varphi_{1,0}(t), \varphi_{0,k}(t) \rangle$ is low pass filter; $h_1(k) = \langle \psi_{1,0}(t), \varphi_{0,k}(t) \rangle$ is high pass filter; $\varphi(t)$ and $\psi(t)$ are scaling function and wavelet function[11-12].

The sampling frequency of the magnetometer is f_s. According to the principle of multi-resolution signal decomposition based on wavelet transform, the frequency band of the wavelet coefficients $d_m(k)$ of m level is $\dfrac{f_s}{2^{m+1}} \sim \dfrac{f_s}{2^m}$.

Let the upper and lower limits of the bandwidth of the magnetic anomaly signal satisfy the following formulas.

$$\begin{cases} \dfrac{f_s}{2^{m_1+1}} \le f_{high} \le \dfrac{f_s}{2^{m_1}} \\ \dfrac{f_s}{2^{m_2+1}} \le f_{low} \le \dfrac{f_s}{2^{m_2}} \end{cases} \tag{7}$$

In formula(7), m_1 is wavelet decomposition level corresponding to the upper bandwidth limit of magnetic anomaly signal, and m_2 is wavelet decomposition level corresponding to the low bandwidth limit of magnetic anomaly signal, and $m_1 < m_2$. By introducing formula (5) into formula (7), the wavelet decomposition level m_1 and m_2 can be calculated. Weighted reconstruction of these decomposition level m_1 to m_2 can effectively enhance the magnetic anomaly signal.

4. Wavelet weighted reconstruction algorithm

The formula of wavelet reconstruction is as follows.

$$c_{m-1}(k) = \sum_{n=-\infty}^{\infty} c_m(n) h_0(k-2n) + \sum_{n=-\infty}^{\infty} d_m(n) h_1(k-2n) \tag{8}$$

The scaling coefficients of m-1 level can be reconstructed from wavelet coefficients and scaling coefficients of m level by formula (8). By analogy, the original signal can be reconstructed[11-12].

According to the selection model of wavelet decomposition level, m_1 and m_2 can be calculated. The original magnetic anomaly signal is decomposed into wavelet coefficients and scaling coefficients of m_2 level, then wavelet coefficients and scaling coefficients between m_1 and m_2 are weighted by the following formula (9) and (10).

$$\hat{d}_m(k) = \begin{cases} a \cdot d_m(k) & m_1 \le m \le m_2 \\ b \cdot d_m(k) & m < m_1 \text{ or } m > m_2 \end{cases} \tag{9}$$

$$\hat{c}_{m_2}(k) = b \cdot c_{m_2}(k) \tag{10}$$

In formula(9) and (10), a and b are Weighting coefficients, $a > 1, 0 < b < 1$. Using $\hat{d}_m(k)$ and $\hat{c}_{m_2}(k)$ to reconstruct the magnetic signal can effectively enhance the underwater target weak magnetic signal.

5. Simulation test

By adding the underwater target simulation signal to the background signal of aeromagnetic measurement, the simulation test signal is constructed. The underwater target simulation signal is shown as figure 3, and the simulation test signal is shown in figure 4.

The wavelet-based adaptive enhancement method proposed in this paper is used to process the simulated test signal, and the enhanced aeromagnetic anomaly signal is obtained as shown in figure 5. The result show that the proposed method can effectively enhance the underwater target weak magnetic signal.

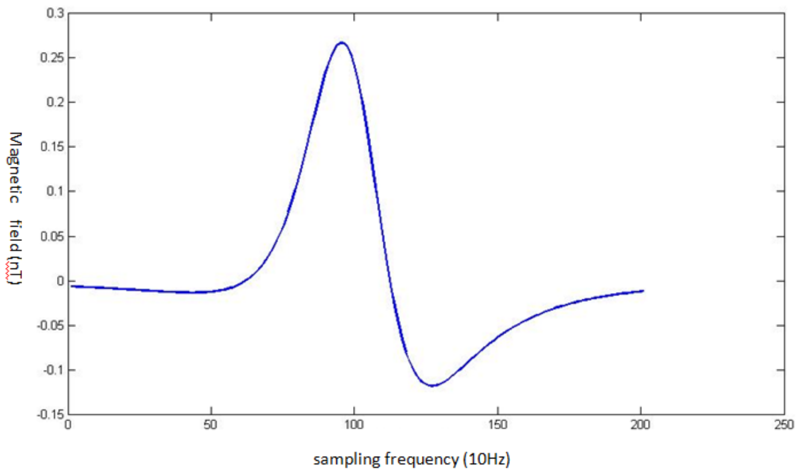

Figure 3 The underwater target simulation signal

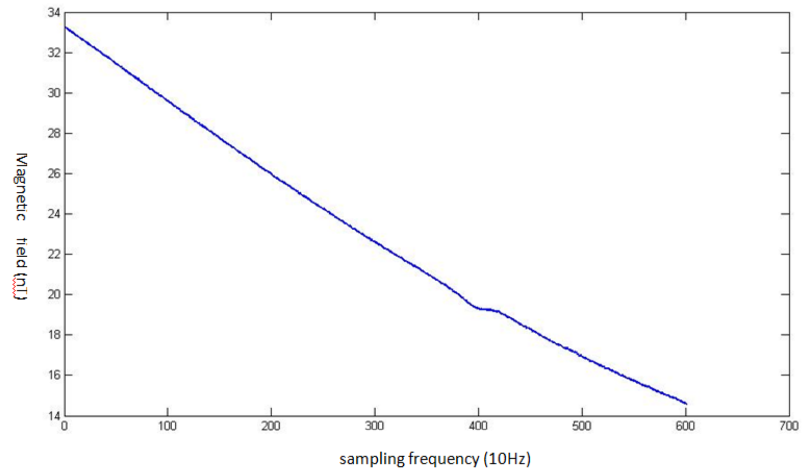

Figure 4 The simulation test signal

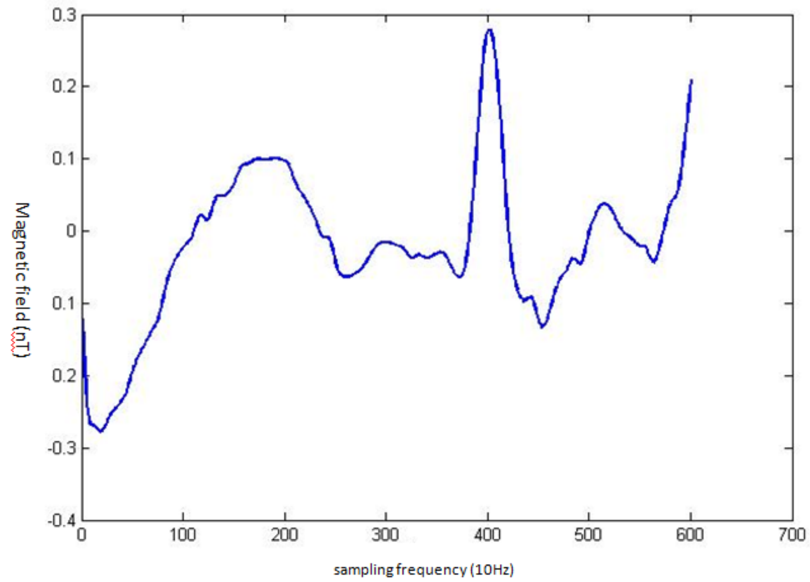

Figure 5 The enhanced aeromagnetic anomaly signal

6. Conclusion

Aiming at the problem of the decomposition level selection in the process of wavelet enhancement , this paper proposed the selection model of wavelet decomposition level of aeromagnetic anomaly signal, and realized adaptive wavelet enhancement of aeromagnetic anomaly signal by weighted reconstruction. The processing results of the simulation test signal show that the method can effectively enhance the weak magnetic signal of underwater target.

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