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Magnetic flux signal extraction method based on wavelet threshold filtering

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Abstract. Magnetic detection based on magnetic flux induction coil is an important means of moving target detection and tracking, which can be applied to various complex environments. Among them, the extraction of the magnetic flux signal of the moving target under complex background conditions is a key technology. This paper first introduces the basic principle of the magnetic flux detection method. According to the different characteristics of the target magnetic flux signal and the noise signal, comprehensively considering the characteristics and applicable range of various signal filtering and noise reduction methods, the wavelet threshold denoising method is selected to carry out the signal. In the laboratory environment, a magnetic flux detection method test system for moving targets was built. The signal extraction method was used to analyse and process the test data and compared with the simulation results. The results show that the filtering method can effectively filter out the Gaussian white noise in the flux signal, separate the signals of different frequencies, and retain the characteristics of the target signal, thus verifying the feasibility and applicability of the method.

1. Introduction

With the development and application [1] of technologies such as drones, small crafts, robots, etc., the detection of the characteristics of speed, height and magnetic moment of these magnetic moving targets has become a subject of great concern [2]. Among them, the detection technology based on the principle of magnetic flux induction has been widely used in some fields, such as automobile monitoring [3]. For the magnetic detection of moving targets under complex background conditions, the detection accuracy is high, and the effective extraction of target feature signals becomes the key technology and important basis of research.

In order to effectively remove the noise interference in the magnetic flux signal, the characteristics of various filtering methods are comprehensively considered for different characteristics of the signal and noise, and the magnetic flux signal is analysed and processed by the wavelet threshold filtering method and verified this method in the laboratory environment.

2. Flux detection signal research

2.1Basic Principles of Flux Detection

The basic principle of flux sensing is based on Faraday's law of electromagnetic induction: for a sized static closed coil, when a magnetic moving target passes through it, it will cause a change in magnetic

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flux, which in turn induces an electromotive force. And the induced electromotive force is linear with the negative value of the magnetic flux change rate of the coil circuit. By quantitative calculation and analysis of the induced electromotive force, certain magnetic characteristic parameters of the moving target can be reversed.

2.2Formula derivation and simulation calculation

In order to quantitatively analyse the change of the induced electromotive force in the closed coil of the magnetic moving target, the magnetic induction intensity of the magnetic dipole at a certain point in space is first derived. The magnetic moment of the magnetic dipole is m, which is convenient for deriving the analysis, and the magnetic dipole is simplified into a circular current with radius R [4].Set the space where the magnetic dipole is filled with a magnetic permeability of μ, according to Biot-Savar's law [5], and deduce the three-component expression of the magnetic induction intensity of the spatial point E(r, φ_0, θ_0).

$$\begin{cases} B_x = \frac{3\mu}{8\pi}\frac{m}{(R^2+r^2)^{\frac{3}{2}}}\frac{r^2 \sin 2\phi_0 \cos\theta_0}{(R^2+r^2)} \\ B_y = \frac{3\mu}{8\pi}\frac{m}{(R^2+r^2)^{\frac{3}{2}}}\frac{r^2 \sin 2\phi_0 \sin\theta_0}{(R^2+r^2)} \\ B_z = \frac{\mu}{2\pi}\frac{m}{(R^2+r^2)^{\frac{3}{2}}}(1-\frac{3}{2}\frac{r^2 \sin^2\phi_0}{R^2+r^2}) \end{cases} \quad (1)$$

The change in the magnetic flux caused by the magnetic moving target passing over the rectangular detecting coil is now derived. From the magnetic flux expression $\Phi = \vec{B}\cdot\vec{S}$, the magnetic flux inside the rectangle can be obtained by integrating the plane around the coil.

Assuming that the direction of the magnetic moment of the target Q(x_q, 0, z_q) is the positive direction of the x-axis, the length of the detection coil is a, the width is b, the magnetic flux of the rectangular coil can be obtained as [6]

$$\Phi = \int_{-\frac{a}{2}}^{\frac{a}{2}}\int_{-\frac{b}{2}}^{\frac{b}{2}} B_z dxdy == -\frac{3\mu m}{4\pi}\int_{-\frac{a}{2}}^{\frac{a}{2}}\int_{-\frac{b}{2}}^{\frac{b}{2}}\left[(x-x_q)^2+y^2+{z_q}^2\right]^{-\frac{5}{2}}\cdot(x-x_q)\cdot z_q dxdy \quad (2)$$

According to Faraday's law of electromagnetic induction, the magnetic flux caused by the movement of the magnetic dipole in the rectangular coil is differentiated from the time t to obtain the induced electromotive force at that moment.

3. Wavelet Filter Extraction Method

According to the characteristics of the magnetic flux signal and the noise signal of the moving target, the method of wavelet threshold filtering is selected to process it.

3.1The basic principle of wavelet threshold filtering algorithm

The wavelet threshold filtering algorithm proposed by Donoho et al. can be used to filter out Gaussian white noise in signals. After the noisy signal is wavelet transformed, the wavelet coefficients are mainly composed of noise and detailed features of the signal. By setting an appropriate threshold, it is considered that the coefficient smaller than the threshold is generated by noise, which is set to zero, and the coefficient larger than the threshold is retained. Thereby suppressing noise in the signal, and at the same time, the signal coefficient can be maximized to obtain the best estimate of the real signal. This method is very sensitive to the selection of the threshold.

The basic steps of signal wavelet threshold denoising mainly include the following three steps [7]:

- Wavelet transform of the signal;
- Wavelet decomposition of threshold quantization of high frequency coefficients. Among them, the determination of the threshold and the selection of the threshold function are key issues;

- Wavelet reconstruction of the signal. Wavelet reconstruction is performed using the low frequency coefficients of the wavelet decomposition and the high frequency coefficients after the threshold quantization processing.

In the process of using wavelet threshold filtering algorithm, the judgment of the importance degree of wavelet coefficients, the selection of threshold function, the determination of threshold and the selection of wavelet base are several key problems.

3.2Filter algorithm parameter selection

Different wavelet bases have different descriptions of the signals. When wavelet transforming a signal, it is always desirable to have the following properties of the selected wavelet base: (1) symmetry or antisymmetry; (2) shorter support; (3) orthogonality; (4) higher disappearance Moment. However, it is often unrealistic to make a wavelet base have the above characteristics at the same time. In the application, only the appropriate wavelet base can be selected according to the specific requirements. In the selection process of the wavelet base, it is necessary to select relatively similar waveforms according to the characteristics of the target signal.

In this paper, the Mexican straw hat wavelet is selected as the wavelet base according to the characteristics of the target signal waveform, and the hard threshold method is adopted to better preserve the signal characteristics. The wavelet function of the Mexican straw hat belongs to the time-frequency localized wavelet function, which can effectively preserve the time-frequency characteristics of the target signal and restore the signal.

The second derivative of the Gaussian wavelet is called the Mexican straw hat wavelet, and its waveform resembles a Mexican straw hat. And its relationship with the target flux signal is shown in Figure 1 and Figure 2.

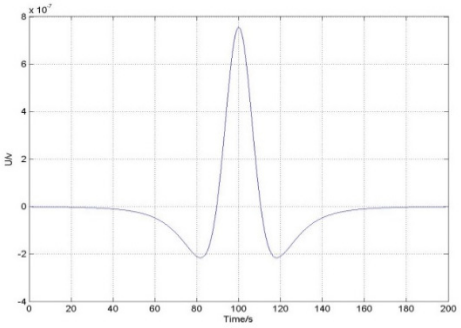


Figure 1. Target flux signal waveform characteristics.

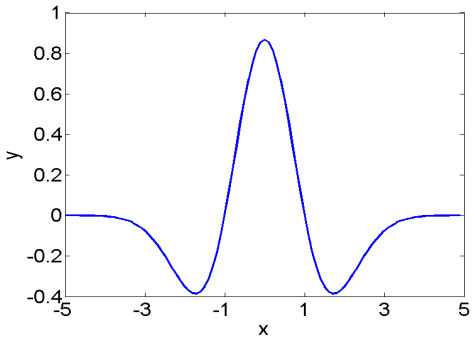


Figure 2. Mexican straw hat wavelet waveform characteristics.

4. Test verification

4.1Test system design

In order to carry out in-depth research on the magnetic flux detection method for moving targets, a test system was designed and developed in the laboratory environment, which can simulate the magnetic target of different motion states through the magnetic flux detection sensor.

The test system is mainly composed of a magnetic flux detection system and a target motion simulation system. Among them, the magnetic flux detection system is composed of a sensor, a signal transmission line, and a signal acquisition and analysis device; the target motion simulation system simulates various motion states of the magnetic target by using a mobile platform to carry a magnetic block. A moving channel of 4.5m long and 2m wide is built on the ground of the laboratory, and the sensor is laid under the channel. The motion simulation system is used to simulate the magnetic target passing through the sensor in different motion states, and the sensing signal is transmitted to the signal acquisition and analysis system for extraction and analysis.

The overall design of the test system is shown in Figure 3.

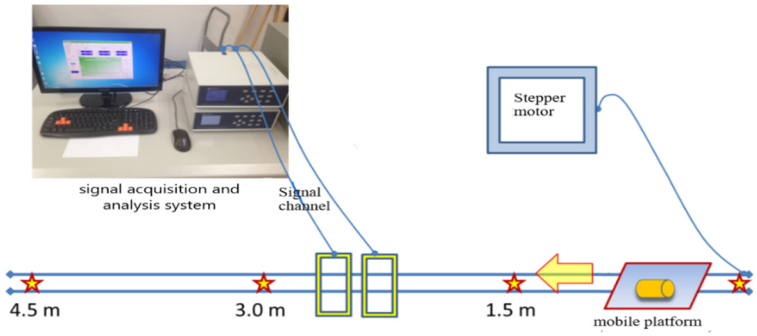


Figure 3. Overall plan of the test system.

4.2Analysis of test results

In the laboratory environment, many experiments were carried out using the system, and the results were analysed by wavelet threshold filtering. The results are as follows.

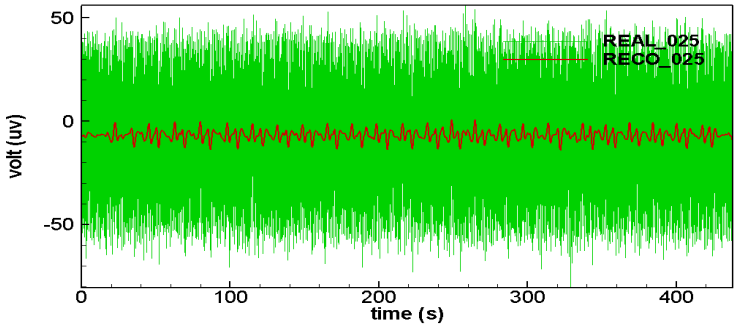


Figure 4. Signal extraction test results

Figure 4 can clearly reflect the extraction effect of the filtering technique. In the laboratory environment, the object with small magnetic moments passes through the detection coil multiple times, and the background interference noise reaches the order of 50 microvolts, while the peak of the target signal is only about 10 microvolts, which is almost completely submerged by noise. The wavelet threshold filtering technique can successfully separate the signal generated by the target 50 round trips.

Through spectrum analysis, it can be found that the frequency distribution of the target signal is mainly at low frequencies (about 0.1-1.0 Hz), while the frequency distribution of laboratory background noise is mainly at higher frequencies (about 20 Hz or more). Therefore, the method of wavelet threshold filtering is beneficial to the extraction and separation of the signal.

In order to further test the extraction and reduction effect of the filtering method on the target signal, the processed target signal and the simulation result are compared and analysed.

The analysis results are shown in Figure 5 (Test condition: the detection coil area is 0.32 m^2, the target moving speed is 0.72 m/s, the height is 0.8 m, the magnetic moment is about 185 $A*m^2$, and the N pole points in the moving direction, single pass).

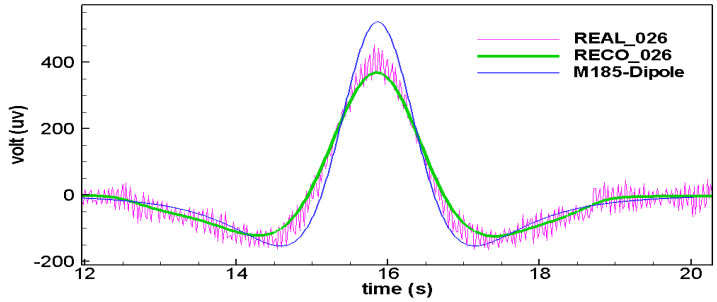


Figure 5. Comparison of test and simulation results.

By comparing with the simulation results, the extraction error of the filtering method can be controlled within the allowable range.

Further, under the background conditions of the laboratory, the test system is used to simulate the magnetic target of different motion states through the sensor, and the mobile platform is used to make the same simulated target repeatedly pass through the induction coil at different speeds and altitudes. The results are shown in Figure 6.

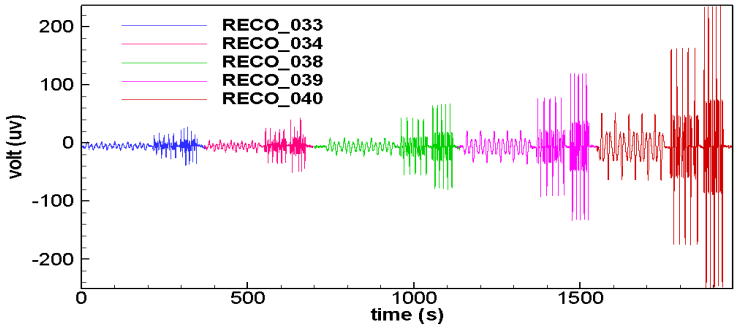


Figure 6. Magnetic flux signal extraction results for different motion states.

The signal in the figure represents the electromotive force signal and the processing result induced by the simulated target reciprocating motion 10 times. And the simulated target magnetic moment is about 180 A*m^2, and the N pole points to the moving direction. The platform moving speed is low speed (0.24 m/s), medium speed (0.72 m/s), and high speed (1.2 m/s), when the height is 2.4, 2.1, 1.8, 1.5, and 1.2 m. For the magnetic targets with different motion states, the extracted magnetic flux signals are different in amplitude and period, and the signal characteristics are obviously different, which is consistent with the simulation results.

5. Conclusion

Based on the theoretical research, combined with the characteristics of the target flux signal and background noise, this paper comprehensively considers the characteristics and applicable range of various signal filtering methods, and selects the wavelet threshold filtering method to analyse and process the signal. By studying the basic principle of the wavelet threshold filtering method, the Mexican straw hat wavelet is selected as the wavelet base, and the test data obtained in the laboratory environment is processed by the hard threshold method. The results of numerical simulation and the experimental results after filtering are compared and verified. The feasibility and applicability of the extraction technique are tested, which is beneficial to the next research and application.

Acknowledgments

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