Research on extremely low frequency magnetic signal detection and fundamental frequency estimation algorithm

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Abstract—The spectrogram of signal is an effective method to analyze the extremely low frequency magnetic field signal. The proposed method is one of the detection algorithm based on the spectrogram. The existence of the target is judged by the harmonics frequency of the spectrum line in the spectrogram. The proposed methods improve the probability of detecting the target and the method can estimate the fundamental frequency of the extremely low frequency magnetic field signal. The simulation and real experiment confirm that the method is effective to analyze the extremely low frequency magnetic field signal.

Key-Words: - spectrogram; extremely low frequency; detection algorithm; fundamental frequency estimation;

1 Introduction

A ferromagnetic target will be magnetized in geomagnetic field. A ship as a ferromagnetic target has a static magnetic field and alternating magnetic field with an extremely low frequency[1].It's called shaft-rate magnetic field[2][3]. The shaft-rate magnetic field of the ship is induced by the corrosion current between the propeller of the ship and the seawater[4].Such an extremely low frequency magnetic field is the signature of the ship or a boat, which has the application in magnetic target detection[5], tracking[6]and so on. The shaft-rate magnetic field of the ship is depicted by Fig.1.The fundamental frequency is the rotation speed of the propeller.

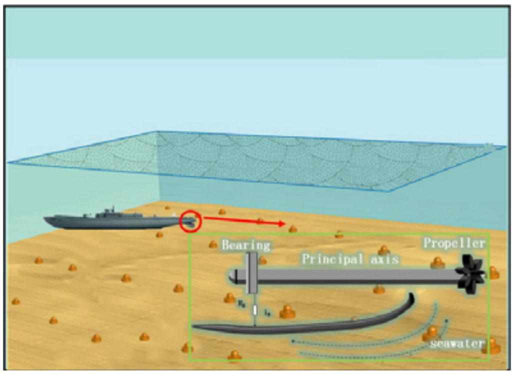

Fig. 1. ship shaft-rate magnetic field of the corrosion current among propeller、shell and seawater

The range of the shaft-rate magnetic field frequency is between 1-7Hz, which belongs to extremely low frequency(ELF)band. Detection and feature extraction is important to analyze the shaft-rate magnetic field signal in intrusion detection[7].It's the first step to the defense system[8]. And then the target's classification[9] and recognition[10]can be realized.

2 The feature of the ship's magnetic field shaft-rate signal

The ship's magnetic field shaft-rate signal is the magnetic anomaly signal which is modulated by the fundamental frequency and harmonics. The shaft-rate magnetic field signal $B(\mathrm{t})$ is shown by (1).

$$B(\mathrm{t}) = \sum_{k=1}^{K} A_k \cos(2\pi \, \mathrm{k} \, \gamma \, \mathrm{t} + \phi_k) \quad (1)$$

A is the amplitude, k is the order of the harmonic frequency, γ is the fundamental frequency and the ϕ is the phase. The spectrum of the ship's magnetic field shaft-rate signal has obviously features of line spectrum instead of continuous spectrum. Hence, the ship's magnetic field shaft-rate signal can be easily distinct in broad band white noise. The ship's magnetic field shaft-rate signal has limited power energy. So the Fourier transform can be use to analyze the ship's magnetic field shaft-rate signal. However, the classical Fourier transform can only reflect the entire spectrum of the ship's magnetic field shaft-rate signal in a period of time. In application, the signal is generally time-varying. The short-time Fourier transform (STFT)[11] is used to analyze the ship's magnetic field shaft-rate signal.

3 The detection and fundamental frequency estimation of the ship's magnetic field shaft-rate signal

Ship's magnetic field shaft-rate signal analysis which based on STFT has two steps: one is judging the existence of the target and then extracting the fundamental frequency which aims to estimating the velocity of movement of the ship.

A. Detection algorithm

The flowchart is shown as the figure 2. At first, the fluxgate magnetometer is used to get the signal, the signal-noise ratio(SNR)is often low because of magnetic noise. In the preprocessing procedure, the function detrend in matlab is used to data to eliminate the linear trend. Then, the high-pass filter is used to eliminate the noise in frequency band which lower than shaft-rate magnetic frequency. The order of the high-pass filter is 45, the stop frequency is set to 0.1Hz, the pass stop frequency is set to 1Hz.The stop band attenuation is -60dB.

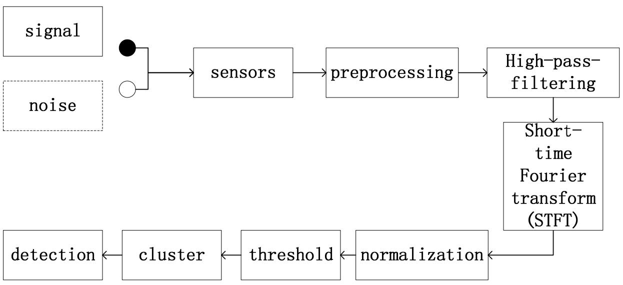

Fig.2. detection algorithm signal processing flowchart

Next procedure is short-time Fourier transform, the length of rectangular window is 10s, sample rate is 50Hz. The continuous time is 1800s.The fundamental frequency is set to 1.8Hz.The simulation ship shaft-rate magnetic field signal and the spectrogram is depicted by the fig 3 and fig 4.The standard deviation σ of the noise is 14.67pT.

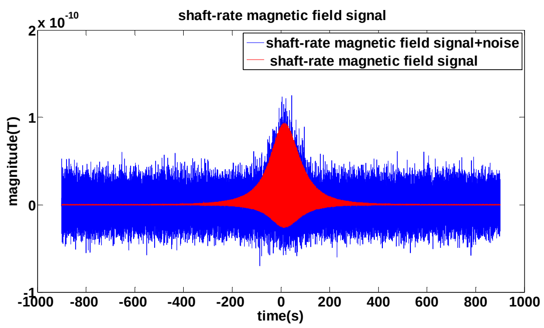

Fig.3. shaft-rate magnetic field signal in white gauss noise with the signal-noise ratio is 3.66dB

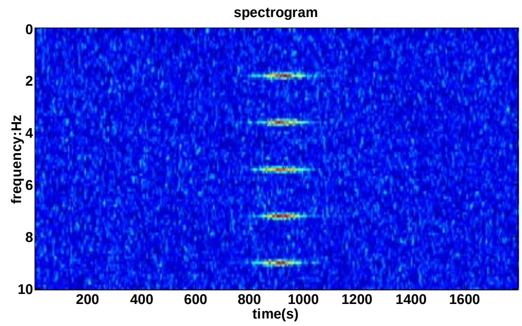

Fig.4. spectrogram of shaft-rate magnetic field signal in white gauss noise with the signal-noise ratio is 3.66dB

The velocity of the ship is 0.3m/s and the closest proximity approach [12] is 30m.The magnetic moment of the magnetic target is (10,10,10).

Next procedure is to normalize the spectrogram, the normalized spectrogram is shown in Fig 5.It's aim to cancel the influence of the peak noise induced by the geomagnetic pulsations.

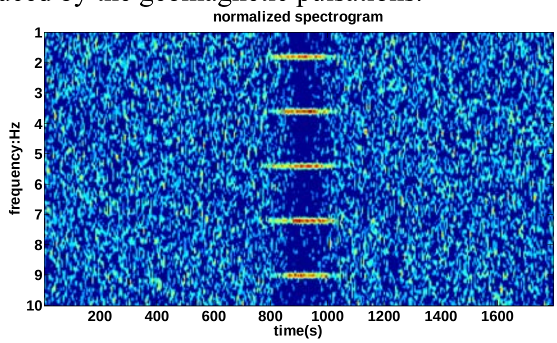

Fig.5. normalized spectrogram

Then the threshold λ of the spectrogram is set to 0.9 σ .The value which beyond the threshold is saved as the possible shaft rate magnetic field frequency bins. The spectrogram after normalization is shown in fig 6.

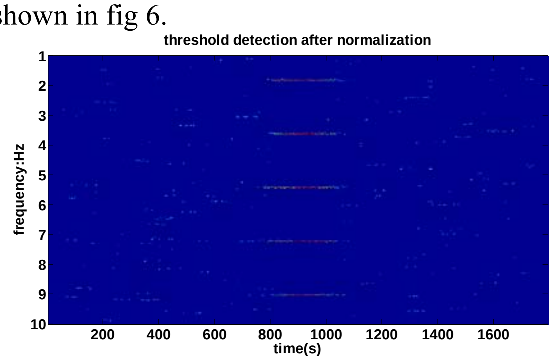

Fig.6. Threshold detection after normalization

Next, the cluster is realized in both frequency and time. The frequency clustering is searching the local max along frequency. If the distance of the two detected frequency bins is lower than 0.1Hz, the two frequency bins are merged in a single frequency bin. Then the time clustering is to choose the frequency bin which satisfied the condition that the sum of the value in 3*10 rectangular around the frequency bin is greater than the 5 times of the maximum of the field. The clustering spectrogram is depicted in Fig 7.

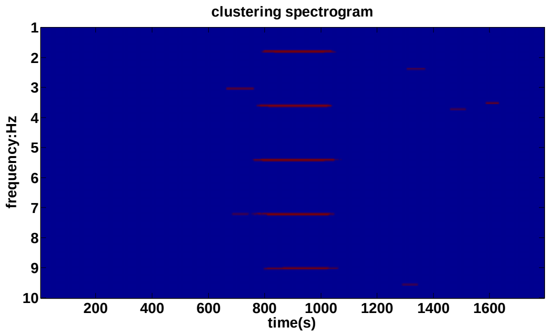

Fig.7. Cluster both in frequency and time domain

Finally, if the frequency of the spectrogram line in Fig.7 is harmonically related, the Δf between the 2 spectrogram line is a constant , the existence of target is confirmed. Otherwise, the target doesn't exist in required data.

The parameter of the detection algorithm is shown in table 1.

Table 1 Parameters of the Detection Algorithm

Symbol	Quantity	Value	Units
m	target magnetic moment	(10,10,10)	$A \cdot m^2$
V0	target velocity	0.3	m/s
λ	frequency detection threshold	0.9	1
σ	standard deviation	0.9	1
CPA	closest proximity approach	30	m
Ts	sampling period	0.02	s

B. fundamental frequency estimation algorithm

1. Choose the frequency of the longest spectrum line as the initial fundamental frequency f_1 . If the frequency of the next spectrum line is 2 times of the initial fundamental frequency (±0.1Hz), the initial fundamental frequency f_1 is final fundamental frequency f_p .

2. If the frequency of the next spectrum line is not 2 times of the initial fundamental frequency (±0.1Hz), and even not several times of the initial fundamental frequency. It's the fundamental frequency buried in geomagnetic $1/f^{\alpha}$ noise [13][14]. It's depicted in Fig.8. If the f_1 is n times of Δf , $\Delta f = f_1 - f_2$, f_1 is the frequency of the longest spectrum line and the f_2 is the frequency of the next longest spectrum line. Final fundamental frequency f_p is regard as Δf .

3. If there is only one spectrum line in the spectrogram, the length of the spectrum line is over 200 Ts ,the f of the spectrum line is regard as fundamental frequency f_p .

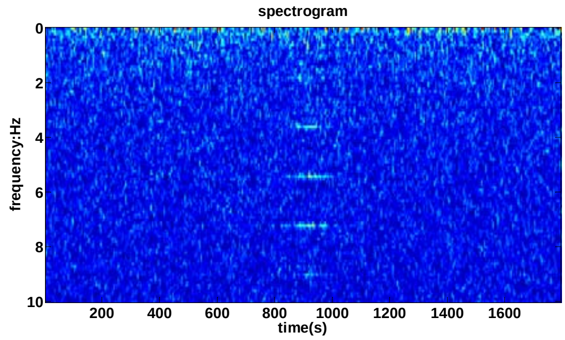

Fig.8. spectrogram of the fundamental frequency buried in $1/f^{\alpha}$ noise

4 The real world experiment

The real ship shaft-rate magnetic field data is difficult to acquire, so the experiment is substituted by receiving the signal in the air which is launched by the magnetic source transmitter in terrene. The experiment implemented in the Prairie, Neimeng province, China. It's shown in Fig.9. The transmitter launched square wave, which frequency is 2Hz.The coils' sampling frequency is 20Hz.

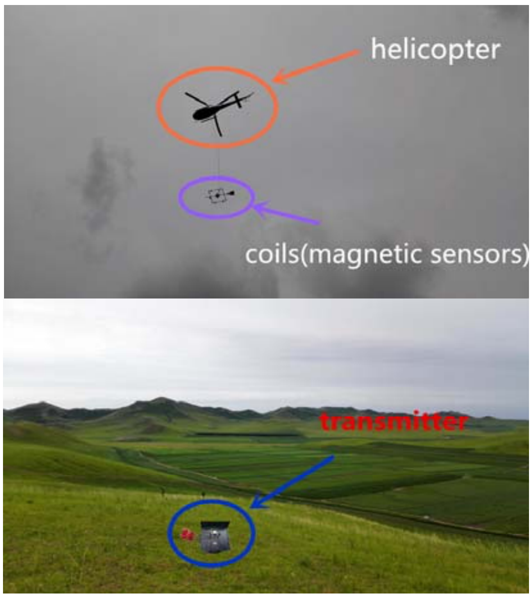

Fig.9. field experiment

The data is pre-processing by a high-pass filter. The handled data is shown in Fig10.

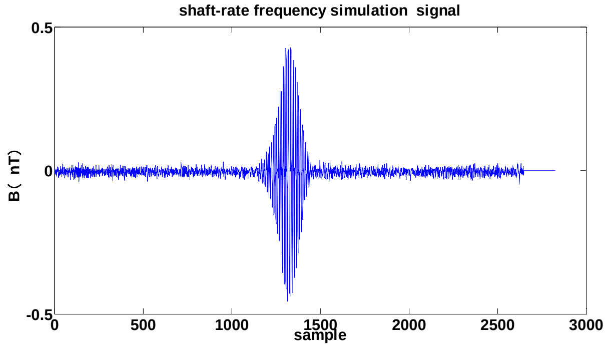

Fig10.shaft-rate frequency simulation signal

The spectrogram of the signal is depicted by fig.11. The range of the displayed frequency is 1-5Hz; the frequency resolution is 0.008Hz. The window is 10s rectangular window.

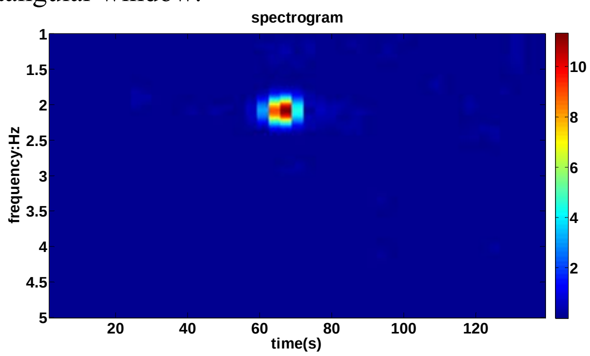

Fig11.shaft-rate frequency simulation signal spectrogram

Then the detection and fundamental frequency estimation algorithm applied to shaft-rate frequency simulation signal. The result is depicted by Fig12.

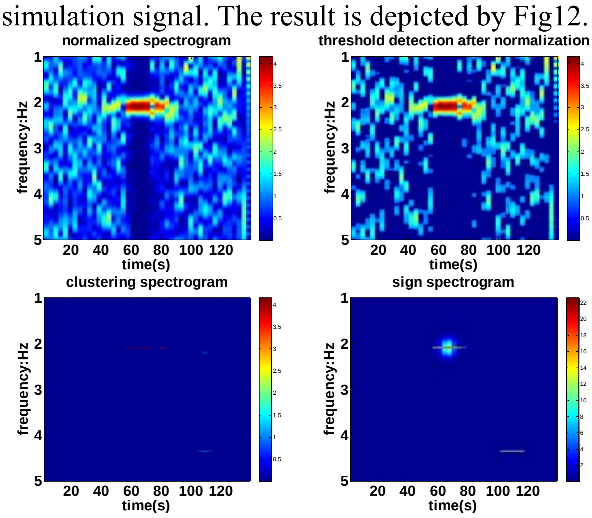

Fig12.detection algorithm result

The detection algorithm detect the target signal accurately and calculated the fundamental frequency of 2.08Hz.

5 summary

Detection and fundamental frequency estimation algorithm in shaft-rate magnetic field signal is researched in this paper. In detection algorithm, the short-time Fourier transform is used to analyze the shaft-rate magnetic field signal. The existence of the target is decided by the length of the spectrum line in the spectrogram. In fundamental frequency estimation algorithm, the fundamental frequency is estimated by the relation between the frequencies of the spectrum line. In high signal and noise ratio, the target and the fundamental frequency can be decided accurately. In low signal and noise ratio, the effect of the algorithm will be significantly worse. The method can is effective for the shaft-rate magnetic field signal analyzing.

References:

[1] Ji D, Wang X J. Extraction SR-ELEF Application Based on MALLAT-ALE Analysis[C]// International Conference on Information Engineering & Computer Science. IEEE, 2009:1-4.

[2] Hao H, Wang H, Yin T. Joint analysis of the shaft-rate magnetic fields for vector sensors[C]// International Conference on Wireless Communications & Signal Processing. IEEE, 2015.

[3] Zhang L, Wang Y, Guo T. Research of extremely low frequency to magnetic dipole in seawater media[C]// International Conference on Information and Communications Technologies. IET, 2015.

[4] Sina M, Ayaz G. Ship's Magnetic Signatures Simulation Using Halbach Magnet Array as Uniform Static Magnetic Field Source[C]// The third Iranian Conference on Engineering Electromagnetic. ICEEM ,2014

[5] Hirota M, Furuse T, Ebana K, et al. Magnetic detection of a surface ship by an airborne LTS SQUID MAD[J]. IEEE Transactions on Applied Superconductivity, 2001, 11(1):884-887.

[6] Gao J, Liu D, Zhou G. Study on the Tracking and Parameter Estimating in Passive Magnetic Detection[J]. Lecture Notes in Electrical Engineering, 2013, 210(1-2):755-764.

[7] Koszteczky, Simon B, Gyula. Sensor Fusion for Intrusion Detection With Sensor Networks[J]. MACRo 2015, 2015, 1(1):275-282.

[8] Ji-Wei S I, Tian Y N, Pan L L, et al. Research on technique of compensative estimation of target height in shore, sea and air collaborative defense system[J]. Systems Engineering & Electronics, 2016.

[9] Qin B, Hu C, Huang S. Target/Background Classification Regularized Nonnegative Matrix Factorization for Fluorescence Unmixing[J]. IEEE Transactions on Instrumentation & Measurement, 2016, 65(4):1-16.

[10] Zeng Z. The application of nonlinear signal detection for ship target recognition[J]. Ship Science & Technology, 2016.

[11] Nishino H, Nakatsu R. Performing STFT and ISTFT in the Microsound Synthesis Framework of the LC Computer Music Programming Language[J]. Journal of Information Processing, 2016, 24(3):483-491.

[12] Sheinker A, Frumkis L, Ginzburg B, et al. Magnetic Anomaly Detection Using a Three-Axis Magnetometer[J]. IEEE Transactions on Magnetics, 2009, 45(1):160-167.

[13] Sheinker A, Shkalim A, Salomonski N, et al. Processing of a scalar magnetometer signal contaminated by 1/ f α, noise[J]. Sensors & Actuators A Physical, 2007, 138(1):105-111.

[14] Nie X H, Pan Z M, Zhang W N. Wavelet Based Noise Reduction for Magnetic Anomaly Signal Contaminated by 1/f Noise[J]. Advanced Materials Research, 2014, 889-890:776-779.