Calculation Error's Correction of Three-component Geomagnetic Field's Marine Survey

Xingle Zhu, Changhan Xiao, Zhenning Yao
College of Electric and Information Engineering, Naval University of Engineering, Wuhan, 430033, China
E-mail: zxl2008edu@163.com

Abstract—**In order to eliminate calculation error, wavelet transform is used to remove noise when navigational data is used to calculate truth-value of three-component geomagnetic field. By introducing Euler attitude rotation matrix, the computing value of geomagnetic vector is decomposed by multi-scale wavelet transform in each frequency. The high-frequency noise is removed and the accurate value of geomagnetic field can be got by rebuilding low-frequency component. Simulation results indicate that the calculated value is identical with setting value and has high precision, which means the method has great applied importance and instructional significance for practical measurement of marine three-component geomagnetic field.**

Keywords-Wavelet transform; calculation error; magnetic field measurement; attitude angle

I. INTRODUCTION

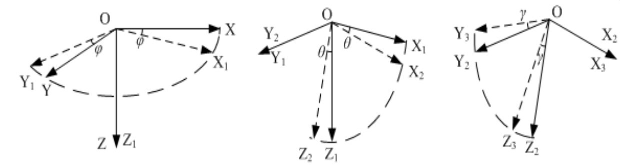
Three-component geomagnetic field is known as important geophysical information, which is widely used in marine physical domain, such as earth-magnetism navigation, detection of underwater obstacles and ship's magnetic defence [1]. It can be measured by satellite, geomagnetic gauging station and marine surveying. The orbit of measuring satellite is high and the precision is not exact enough. Besides gauging stations distribute sparsely on the ocean, it is impossible to get marine magnetic data directly [2]. Marine surveying can be carried on in large area, but it is also influenced by marine factors easily.

Much importance is attached to marine survey for measuring geomagnetic field in foreign countries. America had developed magnetic vector measuring system in 2002, which was dragged behind research ship [3]. Japan had designed STCM (Shipboard Three-Component Magnetometer) in the 80's, and it was applied in marine survey successfully with precision of 50±25nT [4]. The sailing ship would be shaken by marine factors, such as wind, ocean wave and circulation [5]. Then attitude angles come into being between ship and geodetic coordinate systems, and these angles can be measured by navigation equipment. The truth-value of geomagnetic field can be calculated by euler attitude rotation matrix with navigational information [6]. However, there are some errors in the measuring data of ship's navigation system at a certain level, simulation shows that the computing magnetic value would have calculation error for hundreds of nT in extent even though the attitude angle has 0.1° measured error, thus it doesn't accord with the demand of high-precision application including earth-magnetism navigation and ship degaussing.

In order to enhance the precision of navigation system, ref.[7] adopts dual quaternion algebra to update the parameters of attitude model and compute the optimized value; Ref.[8] presents an all-state integrated GPS/SINS navigation system based on MEMS IMU, which can provide accurate attitudes to meet the requirement of vessel attitude compensation. The paper doesn't try to get more accurate attitude angle, but to calculate the geomagnetic value directly. Wavelet transform is used to decompose inexact geomagnetic computed value in multi-scales, and the three-component magnetic value can be reconstructed after noise removing. This method is simple and efficient, and high-precision navigational system isn't required. Simulate indicates that more accurate geomagnetic vector can be obtained, and it has great important guidable meaning for measurement of marine geomagnetic field in practice.

II. EULER ATTITUDE ROTATION MATRIX

The measured error and ship magnetization field are not considered in ideal conditions, and the truth-value could be measured by magnetometer installed strapdown on research ship when the geographic coordinate system is identical with the ship's. However, the attitude angles are brought out between the two coordinate systems when the sailing ship rocks in practice[9]. It can be explained by euler rotation matrix equation, and the details are as follows:



(a) yaw angle φ (b) pitch angle θ (c) roll angle γ

Figure 1. The definition of attitude angle

- The geographic coordinate system is defined as OXYZ, and the ship's is OX'Y'Z', while the two are the same with each other. OZ axis is vertically downward, OX axis orients north, and OY axis orients east.
- When the ship's course changes, OX'Y'Z' revolves on OZ' axis and yaw angle φ appears, the ship's coordinate system becomes $OX_1Y_1Z_1$, as shown in figure 1(a).

- $OX_1Y_1Z_1$ revolves on OY_1 axis and pitch angle θ appears, the ship's coordinate system becomes $OX_2Y_2Z_2$, as shown in figure 1(b).
- $OX_2Y_2Z_2$ revolves on OX_2 axis and roll angle γ appears, the ship's coordinate system becomes $OX_3Y_3Z_3$, as shown in figure 1(c).

γ, θ, φ are all called ship's attitude angles. ***Be*** is assumed as the truth-value of geomagnetic field, and ***Bv*** is assumed as the measured value of magnetometer. The relation between the two values can be described by euler rotation matrix equation.

$$\boldsymbol{B}_v = \boldsymbol{A}\boldsymbol{B}_e \tag{1}$$

A is transform matrix between geography and ship's coordinate system, which could be described as follows[10] :

$$\boldsymbol{A}=\begin{bmatrix}1 & 0 & 0\\ 0 & \cos\gamma & \sin\gamma\\ 0 & -\sin\gamma & \cos\gamma\end{bmatrix}\begin{bmatrix}\cos\theta & 0 & \sin\theta\\ 0 & 1 & 0\\ -\sin\theta & 0 & \cos\theta\end{bmatrix}\begin{bmatrix}\cos\varphi & \sin\varphi & 0\\ -\sin\varphi & \cos\varphi & 0\\ 0 & 0 & 1\end{bmatrix} \tag{2}$$

III. DENOISING METHOD BY WAVELET TRANSFORM

Wavelet transform is an important linear method for time frequency analysis, which window doesn't change in size but the shape is in contrast. It has high frequency and low temporal resolution in low-frequency component, and has low frequency and high temporal resolution in high-frequency component at the same time, so it is called as 'mathematic microscope'. The definition is as follows [11]:

If $\boldsymbol{f}(\boldsymbol{t})\in L^2(R)$, $\boldsymbol{\psi}(\boldsymbol{t})$ is mother wavelet, $\boldsymbol{\psi}(\boldsymbol{t})$ is analytic wavelet, then the inner product between $\boldsymbol{f(t)}$ and $\boldsymbol{\psi}_{a,b}(\boldsymbol{t})$ is known as wavelet transform of $\boldsymbol{f(t)}$ and the formula is as below:

$$W_f(a,b)=\langle f(t),\psi_{a,b}(t)\rangle=\frac{1}{\sqrt{a}}\int_R f(t)\psi^*(\frac{t-b}{a})\mathrm{d}t \tag{3}$$

The measured signal of magnetometer can be described:

$$\boldsymbol{B}(\boldsymbol{t}) = \boldsymbol{b}(\boldsymbol{t}) + \boldsymbol{e}(\boldsymbol{t}) \tag{4}$$

$\boldsymbol{b}(\boldsymbol{t})$ is the truth-value for measured, $\boldsymbol{e}(\boldsymbol{t})$ is the error produced by inexact navigational data. The process is to remove noise and reconstruct the useful part, which is known as wavelet transform. $\boldsymbol{B}(\boldsymbol{t})$ is decomposed to CA1 in low frequency and CD1 in high frequency, while CA1 means the approach of signal and CD1 means the measured error. As the process is going on, $\boldsymbol{B}(\boldsymbol{t})$ can be shown as below:

$$B(t)=CAn+CDn+CD(n-1)+...+CD2+CD1 \tag{5}$$

The low-frequency coefficients are reconstructed to regain the true part of signal after n-layer wavelet transform.

IV. EXPERIMENT RESULT AND DISCUSS

A. Characteristic analysis

The geomagnetic true value is set as ***Be***(unit: nT), ***Be***=[36000, 19000, 28000]. In ideal conditions, the ship magnetization field is not considered and the magnetometer has no measured error. The attitude angles are set to satisfy the change rule of sine and cosine in a circle, and the measured value can be simulated by equation (1). In fact, the navigational data is not precise enough, thus the calculating value contains error in a certain extent. The precision of navigation system is set by 0.1º, and the measured value can be computed by navigational parameters simulated by the above formula. The range is set as the difference between maximal and minimal value, △B is defined as the maximal distance between set and measured value, besides var stands for the mean square deviation. The details are as follows:

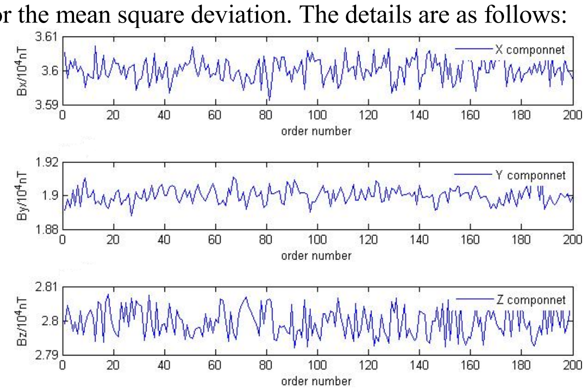


Figure 2. The computing value of geomagnetic vector

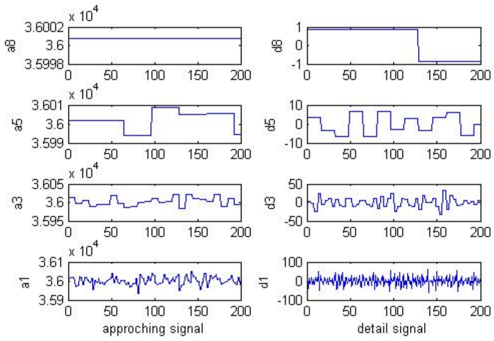
TABLE I. STATISTIC INDEXES OF GEOMAGNETIC VECTOR'S COMPUTED VALUE (UNIT: NT)

	Set	Max	Min	Range	△B	Var
Bx	36000	36076.86	35926.72	150.14	76.86	32.9289
By	19000	19112.06	18889.58	222.48	112.06	46.4549
Bz	28000	28079.02	27924.28	154.74	79.02	40.8145

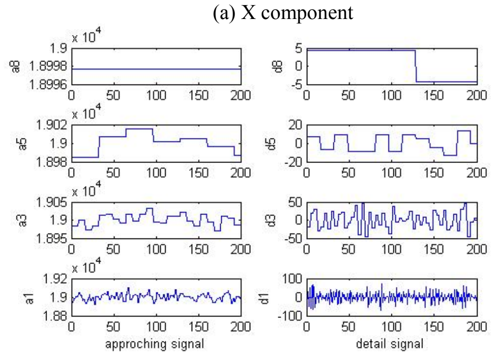
From the above result, it is shown that geomagnetic calculated value has fluctuation range for hundreds of nT in three components even though navigational parameters has measured error for 0.1°, which doesn't meet the high-precision demand of application for geomagnetic navigation and ship degaussing, thus it is necessary to denoise the computing value.

B. Denoise by wavelet transform

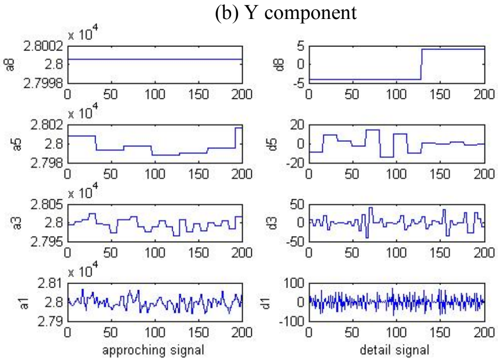
It is important to choose appropriate wavelet function when multi-scales wavelet transform is used for noise removing, different function can stand out different signal's character. Because a series of measured values are smooth and steady signal in ideal conditions, db1 wavelet function is chosen to decompose in multi-scales. Figure 3 is the effect graph of the result using bd1 function, and the calculated value is decomposed in 8 layers, while a1~a8 are the gradual approach of true signal and d1~d8 are the high-frequency noise in each layer. △B is the deviation before denoise and △B1 is the deviation afterwards.



(a) X component



(b) Y component



(c) Z component

Figure 3. Noise removing result using wavelet transform

TABLE II. GEOMAGNETIC VECTOR'S COMPUTED VALUE USING WAVELET TRANSFORM (UNIT: NT)

	Set	Compute	△B	△B1
Bx	36000	36001	76.86	1
By	19000	18997	112.06	3
Bz	28000	28001	79.02	1

From graph 3 and table 2, it is known that the low-frequency signal is balanced and the high-frequency noise is eliminated, thus the true components are obtained. Comparing to the set value, the three components have deviation not exceeding 5 nT after reconstruction, which means that wavelet transform can be used in measurement of marine geomagnetic field, therefore the problem is solved when the inexact navigational data is used to compute the truth-value directly.

V. CONCLUSIONS

Wavelet transform is used to remove noise because the calculated value of geomagnetic vector would be tampered by inexact navigational information. The calculated value is multi-layer decomposed to reduce high-frequency noise by chosen right wavelet function, then accurate geomagnetic value can be obtained. Simulate result shows that the calculated value is precise enough for practical application, and it had great guiding significance for measurement of marine geomagnetic field.

REFERENCES

[1] B.B Fan, J.N Xu, and H.J Zhou,"Novel method of vessel heading and attitude resolution,". Journal of Chinese Inertial Technology,china, vol.16, pp.586-588, 2008.

[2] S.Macmillan, J.M.Quinn,"The derivation of world magnetic model 2000". British Geological Survey, Edinburgh, 2000.

[3] J S Gee, S C Cande,"A Surface-towed Vector Magnetometer," Geophysical Research Letters, china, vol.29, pp.151-154, 2002.

[4] Novuhiro Isesaki,"A New Shipboard Three-component Magnetometer," Geophysics, vol.51, pp.1992-1998, 1986.

[5] X.B Jia, Y Fan,"A key technology research on inertia-aided GPS-based ship attitude determination system," Ship science and technology, china, vol.32, pp.74-77, 2010.

[6] H.Yan, C.H Xiao,"A method of measuring three-component geomagnetic field on ocean," Journal of Naval University of Engineering, china,vol.17, pp.80-83, 2005.

[7] L.L Xia, L Zhao, F.M Liu, et al,"Research on attitude updating algorithm based on dual quaternion for attitude and heading reference system," Journal of System Simulation, china, vol.20, pp.276-280, 2008.

[8] Y.R Sun, J.Y Liu, W Chen, et al,"Vessel attitude system for multibeam echosounding," Journal of Nanjing University of Aeronautics &Astronautic, china, vol.35, pp.356-360, 2003.

[9] C.H Xiao, Study of ship's magnetic defence techniques and the anti-interference method for degaussing system. Wuhan, Huazhong University Science and Technology, 1998.

[10] K Li, S Huang, H Zhao, "Transformation of GPS coordinate systems and its application in attitude determination," Command Control & Simulation, china, vol.30, pp.113-115, 2008.

[11] Z.G Wang,"Study on noise removing by wavelet transform for dynamic measuring of ship magnetic field," Ship Electronic Engineering, china, vol.31, pp.158-160, 2011.