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Investigation of the so-called Magnetic North Immeasurable Area in the South Sea of Korea by a newly assembled three axis Magnetometer

Mutaek LIM*
KIGAM
limmt@kigam.re.kr

Youngsue PARK
KIGAM
yspark@kigam.re.kr

Younghong SHIN
KIGAM
yhshin@kigam.re.kr

Hyoungrae RIM
KIGAM
rhr@kigam.re.kr

Hyunkey JUNG
KIGAM
hkjung@kigam.re.kr

Younsoo LEE
KIGAM
leeys@kigam.re.kr

Kyongo KIM
KIGAM
kokim@kigam.re.kr

Taehwan JEON
UST
thfarmer@hotmail.comr

KIGAM (Korea Institute of Geoscience and Mineral Resources): 124, Gwahak-ro, Yuseong-gu, Daejeon, 305-350, Korea
UST (University of Science and Technology): 217, Gajeong-ro, Yuseong-gu, 305-350, Korea

SUMMARY

An area exists on the South Sea of Korea where the magnetic compass is said to turn round and round not giving a fixed direction to the navigator.
We newly assembled a three axis magnetometer system composed of a three axis fluxgate magnetometer, a GNSS compass, a two axis clinometer, and a multi-channel data logger, to investigate if there really exists such an area. We supposed that the horizontal component of the vectorially measured magnetic field on such an area will be too small to maintain the magnetic compass's needle to one fixed direction. We processed the measured data mainly through two steps. Firstly we transformed the random coordinate system into a fixed coordinate system, i. e., into the geographical coordinate system. Secondly we performed an inversion to eliminate the effect of the ship itself from the measured data.
On the finally achieved anomaly map we could not find such an area where the horizontal component is so small that it could not maintain the magnetic compass's needle to a fixed direction.
We conclude that such statement about the existence of the so-called magnetic north immeasurable area on the South Sea of Korea does not have a strict scientific base.

Key words: three axis magnetometer, three axis fluxgate sensor, GNSS compass, two axis clinometer, magnetic compass.

Introduction

An area to the south from the Cheongsan Island, Wando-gun, Jeollanamdo Province, on the South Sea of Korea(Figure 1) exists, where comes down a legendary statement that the magnetic compass is said to turn round and round there, not giving a fixed direction to the navigator and having arisen some marine accidents. However, we could not find any scientifically explanatory documents of the nature of that area.

Therefore, we newly assembled a three axis magnetometer system mainly composed of a three axis fluxgate sensor, a GNSS compass, a two axis clinometer, and a multi-channel data logger of which the first three modules were positioned so that their axes coincide. The purpose is to investigate if there really exists such an area on the supposition that there the horizontal component of the vectorially measured magnetic field will be too small to maintain the magnetic compass's needle to one fixed direction.

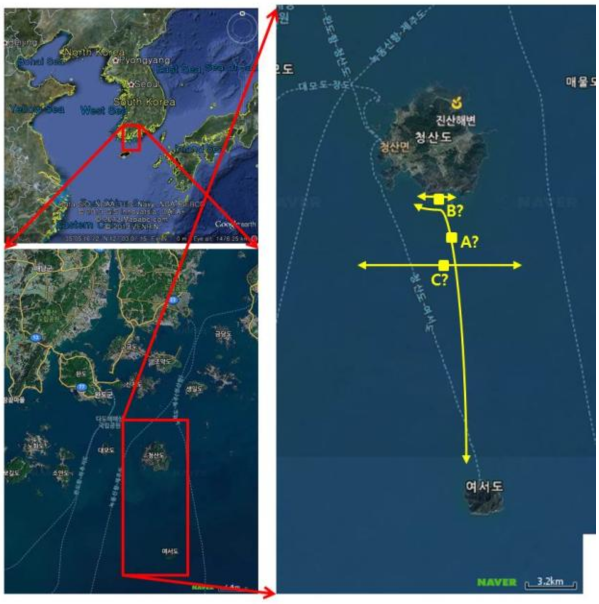

Figure 1. Study Area.

We processed the measured raw data mainly through two steps.
Firstly we transformed the random coordinate system different on every measuring point into a fixed coordinate system, i. e., into the geographical coordinate system using the azimuth of the ship acquired by the GNSS compass and two tilts of the ship acquired by the two axis clinometer.
Secondly we performed an inversion to eliminate the effect of the ship itself from the measured data. During the inversion, as the input data, we used the data set which was measured on a very narrow area by circling the ship several turns so that we can regard the sum of the earth's magnetic field and that generated by the geology to be the same. Based on the inverted induced magnetic moment and the remanent magnetic moment, we forwardly calculated the magnetic effect of the two magnetic moments of the ship itself and subtracted them from the reoriented data set derived after the first step.

On the finally achieved anomaly map we could find if there really exists such an area where the horizontal component is so small that it could not maintain the magnetic compass's needle to a fixed direction.

A Newly Assemble Three Axis Magnetometer System

We newly assembled a three axis magnetometer system mainly composed of a three axis fluxgate magnetometer of model FVM-400 of MEDA Co., USA (MEDA, 2002), a GNSS compass of model SSV-100 of Hemisphere Co., Canada (Hemisphere, 2010), a two axis clinometer of model MD900-T of Applied Geomechanics Co., USA (Applied Geomechanics, 2006), and a multi-channel data logger based on embedded computing system chip. We gave the name KGMDL (KIGAM's Geophysical Multi-channel Data Logger) ver. 0.98 to the assembled system. Figure 2 shows the schematic diagram of it. We positioned the first three modules so that their axes coincide to one common rectangular coordinate system for the ease of the later data processing. The Y axis of the two axis clinometer being opposite to the common coordinate system, we can overcome this problem by multiplying the Y axis tilt by (-1) in the data processing.

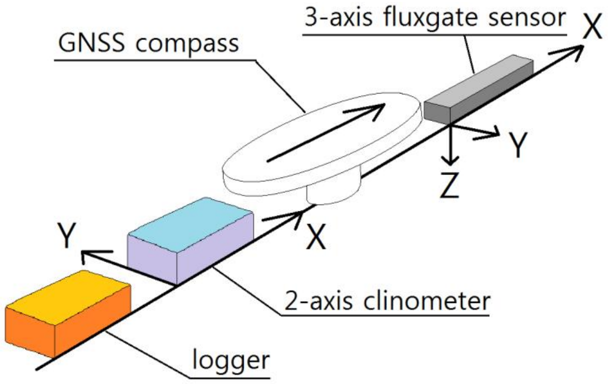

Figure 2. Schematic Diagram of the assembled System.

The system outputs mainly x, y, z component of magnetic field, azimuth of the ship, time, latitude, longitude, x, y axis tilt to each one line per second into the raw data file.

Surveyed Area

We heard the statements saying about the possibility of the existence of such magnetic north immeasurable area from many old inhabitants of the island and we could summarize them so that the possible routes passing the area in issue can be marked as A?, B?, and C? in Figure 1.

So, we deployed the east-west survey lines of length about 3 km and with the line spacing about 200 m, the south-north width being about 4 km. Figure 3 shows the deployed survey lines.

We acquired the input data for the inversion on a very narrow area by circling the ship several turns marked on Figure 3.

The depth of this area to the bottom is 53 +/- 5 m. The coordinate of the area's center is (126° 53′ 40″ E, 34° 08′ 01″ N, WGS84 coordinate system), and the magnetic field's components calculated from IGRF (Maus, S. et al., 2005) are b_n = 31425 nT, b_e = -3850 nT, b_h = 31660 nT, b_z = 37412 nT, total = 49010 nT, decl = -7.0°, incl = 49.8°.

Processing of the Measured Raw Data

The measured magnetic field $\vec{B}_{meas}$ in whole includes the earth's magnetic field $\vec{B}_{earth}$, that generated by geology $\vec{B}_{geol}$ and that generated by the ship itself $\vec{B}_{ship}$, and the last includes again the induced magnetic field $\vec{B}_{ship/ind}$ and the remanent magnetic field $\vec{B}_{ship/rem}$ as in equation (1).

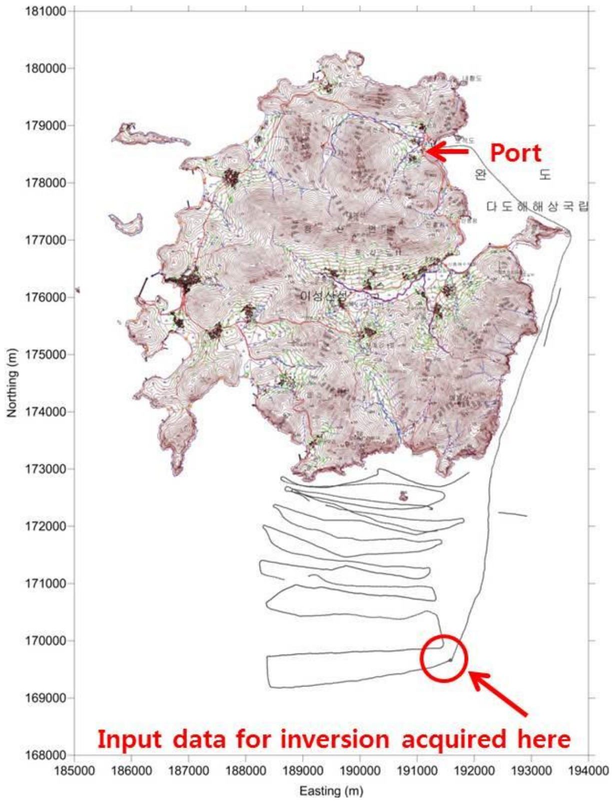

Figure 3. Surveyed Area.

$$\vec{B}_{meas} = \vec{B}_{earth} + \vec{B}_{geol} + \vec{B}_{ship/ind} + \vec{B}_{ship/rem} \quad (1)$$

Prior to the interpretation, we should transform the random coordinate system different on every measuring point into a fixed coordinate system, i. e., into the geographical coordinate system to make all the measured data as if they were measured on the common geographical coordinate system.

What we want to deal for the interpretation is $\vec{B}_{geol}$ only, or $\vec{B}_{earth} + \vec{B}_{geol}$ as $\vec{B}_{earth}$ is almost the same in a narrow area and so can be eliminated easily. Therefore, $\vec{B}_{ship/ind} + \vec{B}_{ship/rem}$ should be eliminated in any case.

Coordinate Transformation

In a three dimensional space, to change the vector $\mathbf{V}_1(x_1, y_1, z_1)$ measured on a random three axis rectangular coordinate system $X_1Y_1Z_1$ into the vector $\mathbf{V}_f(x_f, y_f, z_f)$ measured on a fixed common three axis rectangular coordinate system $X_fY_fZ_f$ is equivalent to to perform three times of inner rotation in turn round the proper axes as center by three Euler angles γ, δ, ε(Arfken, 1985). The assembled system measures the azimth of the ship η by the GNSS compass and the two tilts α and β along the x and y axis respectively by the two axis clinometer. According to Jeon et al. (2013) this procedure can be done as in equation (2).

$$\mathbf{V}_f = \mathbf{R}_z(\varepsilon)\mathbf{R}_x(\delta)\mathbf{R}_z(\gamma)\mathbf{V}_1 \qquad (2)$$

$$\begin{pmatrix} x_f \\ y_f \\ z_f \end{pmatrix} = \begin{pmatrix} \cos\varepsilon & -\sin\varepsilon & 0 \\ \sin\varepsilon & \cos\varepsilon & 0 \\ 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} 1 & 0 & 0 \\ 0 & \cos\delta & -\sin\delta \\ 0 & \sin\delta & \cos\delta \end{pmatrix} \begin{pmatrix} \cos\gamma & -\sin\gamma & 0 \\ \sin\gamma & \cos\gamma & 0 \\ 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} x_1 \\ y_1 \\ z_1 \end{pmatrix}$$

, where γ, δ, ε are derived using η, α, and β as follows;

$$\gamma = \frac{\kappa}{|\kappa|}\cos^{-1}(\cos\kappa\cos\alpha)$$

$$\delta = \tan^{-1}\left(\frac{\tan\alpha}{\sin\kappa}\right)$$

$$\varepsilon = \eta - \kappa$$

$$\kappa = -\tan^{-1}\left(\frac{\sin C}{\dfrac{\tan\beta}{\tan\alpha} + \cos C}\right)$$

$$C = \cos^{-1}\left(\frac{(\csc\alpha)^2 + (\csc\beta)^2 - (\csc\alpha\cos\alpha)^2 - (\csc\beta\cos\beta)^2}{2(\csc\alpha\cos\alpha)(\csc\beta\cos\beta)}\right)$$

Figure 4 shows the relation among the angles.

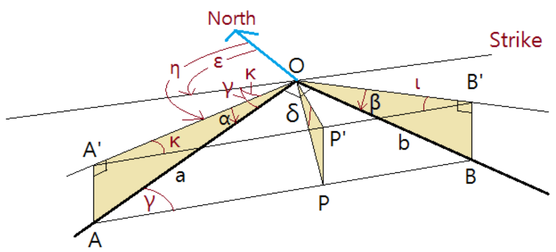

Figure 4. Relation among Angles.

Figure 5 shows the measured raw data on the random coordinate system for each measured point. b_x, b_y, and b_z is magnetic field's component measured on x, y, z axis respectively.

Putting in consideration together Figure 2, Figure 3, and the IGRF derived values, b_n = 31425 nT, b_e = -3850 nT, b_h = 31660 nT, b_z = 37412 nT, total = 49010 nT, decl = -7.0°, incl = 49.8°, we can know that the measured raw data shows us what we imagined. For example, if the ship proceeds to the west then the b_y component will be near to 31660 nT, but if it is to the east then near to -31660 nT.

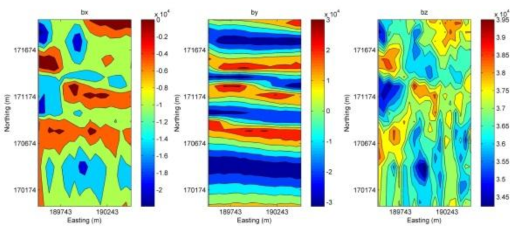

Figure 5. Distribution of Raw Data b_x, b_y, b_z Measured on Random Coordinate System for Each Point.

Figure 6 shows the vector $\mathbf{V}_f(x_f, y_f, z_f)$ as if measured on the fixed common three axis rectangular coordinate system, in our case, geographical coordinate system or NEZ system after coordinate transformation from the vector $\mathbf{V}_1(x_1, y_1, z_1)$ measured on a random three axis rectangular coordinate system $X_1Y_1Z_1$. We can see on the Figure that the north component is near to 30000 nT, east component near to -4000 nT, and vertical component near to 37000 nT respectively not far from the IGRF derived values, b_n = 31425 nT, b_e = -3850 nT, b_h = 31660 nT, b_z = 37412 nT, total = 49010 nT.

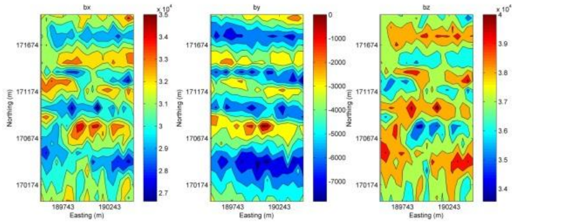

Figure 6. Distribution of b_n, b_e, b_z Component Data after Coordinate Transformation.

We see linearities on the Figures, which imply us the existence of the magnetic effects with directionality of the ship itself not yet eliminated well.

Elimination of the Ship's Magnetic Effects by Inversion

We can eliminate $\vec{B}_{ship/ind} + \vec{B}_{ship/rem}$ in equation (1) by calculating the induced magnetic moment and the remanent magnetic moment of the ship by inversion, by forward calculating the magnetic effects of the ship and finally by subtracting them from the data on the Figure 6. We used the following equation (3) in Blakely(1996, p 75) as the core equation of the inversion, and the Adaptive Simulated Annealing (ANA) as the inversion algorithm.

$$\vec{B} = C_m \frac{m}{r^3}\left[3\left(\vec{m}_u \cdot \vec{r}_u\right)\vec{r}_u - \vec{m}_u\right] \qquad \ldots\ldots\ldots\ldots\ldots (3)$$

For the inversion, as the input data we used the data set which was measured on a very narrow area by circling the ship several turns so that we can regard the sum of the earth's magnetic field and that generated by the geology to be the same.

Figure 7 shows the input data for the inversion in upper line, and the forward calculated magnetic effects generated by the ship itself.

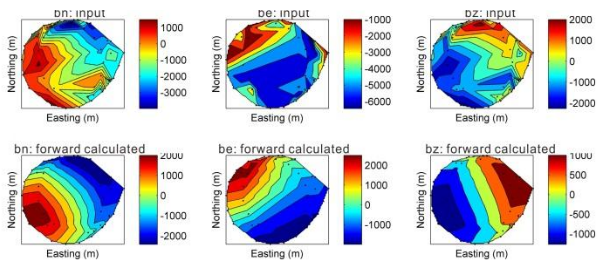

Figure 7. Input data b_n, b_e, b_z for the inversion (upper) and forward calculated magnetic effects of the ship (lower).

Table 1 shows the result of the inversion or the features of the induced magnetic moment and the remanent magnetic moment of the ship, i. e., relative position, intensity, declination, and inclination of each magnetic moment calculated by inversion.

	position of mag. mom.	intens. mag. mom.	dec.	inc.
ind.	0.7 m from reference GPS antenna 82.0 deg. from heading 2.1 m down from mag. sensor	60	-7.0	49.8
rem.	4.7 m from reference GPS antenna 202.0 deg. from heading 0.8 m down from mag. sensor	1837	199.4	45.3

Table 1. The result of the inversion.

Figure 8 shows the relative location of the induced and remanent magnetic moment with the GNSS reference antenna's phase center as (0, 0, 0) and with the heading direction as +x.

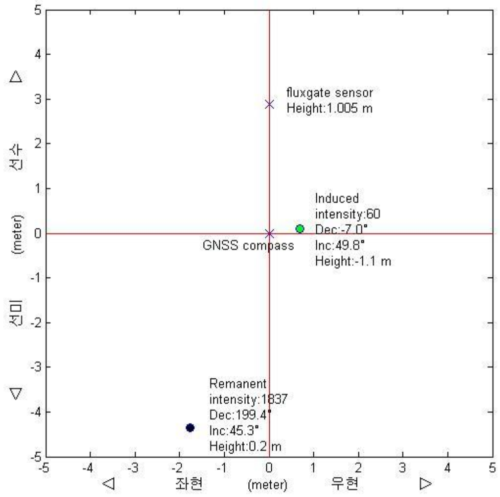

Figure 8. The relative position of the induced and remanent magnetic moment calculated by inversion.

And Figure 9 shows the final distribution of vector $\mathbf{V}_f(x_f, y_f, z_f)$ after elimination of the magnetic effects generated by the induced and the remanent magnetic moment of the ship itself. We can see from the Figure9 that a considerable portion of the distinct linearities on all three components on the Figure 6 disappeared and the differences (high – low) on all three components on the Figure 6 also diminished much. These two imply us that much but not all of the magnetic effects generated by the existence of the ship itself were eliminated from the previous Figure 6.

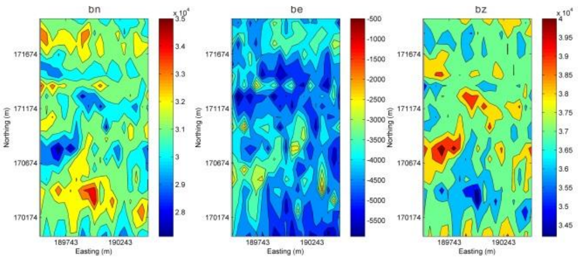

Figure 8. Distribution of the final vector (b_n, b_e, b_z) after elimination of the magnetic effects generated by the ship itself.

Does there really exist the so-called Magnetic North immeasurable Area ?

Figure 9 shows there distribution of the declination calculated from b_n and b_e components of the Figure 8.

Putting in consideration the fact that the IGRF derived declination in this area is -7.0°, the calculated declination range mainly from -10° to -4° centred on -7.0° because of the remanence of the ship's magnetic effects, and horizontal component of the magnetic field of this area can not be smaller than 30000 nT from the b_n component on the central figure of the Figuat 8. So, there can not exist an area where the horizontal component is so small that it could not maintain the magnetic compass's needle to a fixed direction.

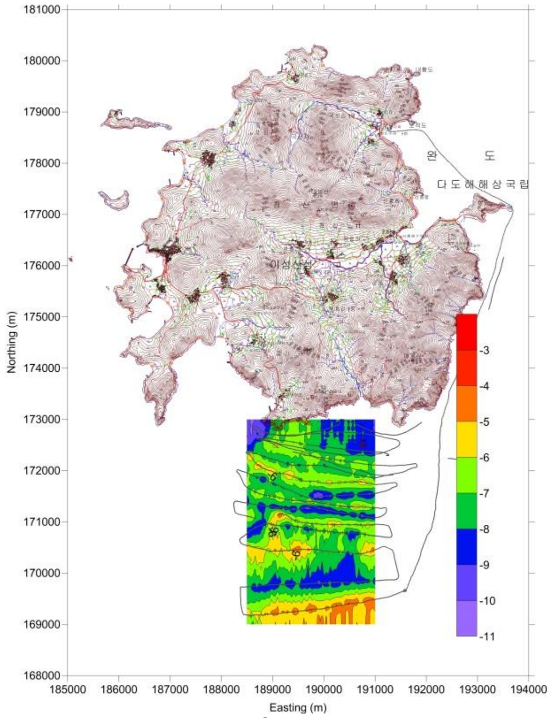

Figure 9. Distribution of the declination calculated from b_n and b_e components of the Figure 8.

Therefore, we conclude that such statement about the existence of the so-called magnetic north immeasurable area in the South Sea of Korea does not have a strict scientific base.

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