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Research on the influence and compensation method of the gravity disturbance on the TT&C ship's INS

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Abstract. The precision of Inertial navigation system (INS) is closely correlated with the accuracy of gravity compensation. Aiming at the INS of the TT&C ship, the gravity deflection of the vertical (DOV) of the task regions and the accuracy of inertial navigation influenced by the DOV were investigated. Finally, the method compensating the gravity disturbance in the mechanical formulas of INS was proposed.

Introduction

The measurement and control of spacecraft must be carried out simultaneously with the measurement and control equipment to track the measured target, while the position and attitude of the surveying ship must be measured synchronously by means of ship position equipment. In general, the accuracy of ship position can be ensured by GNSS positioning equipment on ship, so the attitude measurement error becomes the main error source of target acquisition and location. The accuracy of attitude measurement is mainly ensured by INS.

In the inertial navigation system, the accelerometer is used to measure the vector of the position of the carrier, and the absolute acceleration of the carrier can be obtained by compensating the gravitational acceleration from the measured force. According to the relationship between the absolute acceleration and the relative acceleration, the inertial navigation system further, the relative velocity and position of the carrier are obtained. In the vicinity of the Earth, the main component of gravitational acceleration is gravity acceleration. In inertial navigation calculations, the gravity vector is usually calculated using the normal gravity formula based on the Earth's reference ellipsoid. Due to the irregular shape of the earth and the uneven internal mass, the Earth reference ellipsoid and the geoid do not match exactly. The actual gravity vector is deviated from the value calculated by the normal gravity formula, which is the gravity disturbance. The vertical component is called gravity anomaly, and the horizontal component is Deflection of the vertical. The gravity disturbance error, especially the vertical deviation is an important error source of inertial navigation system. In the low-precision navigation applications, due to the inertia of the device itself is relatively large error, the use of normal gravity model can meet the demand. However, in the inertial navigation system with high precision, the influence of the gravity disturbance error becomes more and more prominent as the accuracy of the inertial device is increasing, which becomes the most important error factor in the inertial navigation system.

The component of the vertical deviation in the meridional direction is called the north-south vertical deviation, which causes the projection of the gravity vector in the northward direction of the reference ellipsoid; the component in the unitary circle direction is called the east-west perpendicular Deviation, which causes the projection of the gravity vector in the eastward direction of the reference ellipsoid. When the horizontal component of the gravity vector is much smaller than the normal gravity value, the vertical deviation and the horizontal component of the gravity vector have the following approximate relationship:

$$\xi \approx \frac{\Delta g_y}{g} \tag{1}$$

$$\eta \approx \frac{\Delta g_x}{g} \tag{2}$$

High accuracy inertial navigation gravity field model

Normal gravity model.

Normal gravity is derived from the sum of the gravitational and centrifugal forces of the normal ellipsoid and can be represented by a simple analytic expression. Since the direction of the normal gravity vector is just along the normal direction of the ellipsoid, the normal gravity vector has only the third component in the local horizontal coordinate system, and the other two components (the two horizontal components) are zero. Thus, the normal gravitational force required for the mechanical arrangement of the local horizontal coordinate system simplifies the problem of a scalar calculation formula.

The normal gravitational formula at any point on the ellipsoid is the Somigliana formula:

$$\gamma = \frac{a\gamma_e \cos^2\varphi + b\gamma_\rho \sin^2\varphi}{\sqrt{a^2\cos^2\varphi + b^2\sin^2\varphi}} \tag{3}$$

Formula (3) is a tight formula, but it is not suitable for fast, especially, but not suitable for fast, especially real-time navigation calculation requirements. To this end, the above equation developed to facilitate the computer on the series of numerical calculation of the form:

$$\gamma_n = \gamma_a\left(1 + a_1\sin^2\varphi - a_2\sin^2 2\varphi\right) \tag{4}$$

For the WGS 84 coordinate system, the ellipsoid parameter is the recommended value of the 17th General Assembly of the International Union of Geodesy and Geophysics IUGG, GRS80 ellipsoid, the corresponding normal gravity formula is:

$$\gamma_n = 9.780\,3253\left(1 + 0.005\,3022\sin^2\varphi - 0.000\,0058\sin^2 2\varphi\right) \tag{5}$$

Spherical harmonic model of gravity field.

The spherical harmonic model of the earth's gravity field is a kind of basic parameter set which is used to describe and determine the gravitational field. It is an approximate expression of the real gravity field. At present, the habit of using the global perturbation of gravity spherical harmonic series expansion expression:

$$T(r,\theta,\lambda) = \frac{GM}{r}\sum_{n=2}^{\infty}\left(\frac{R}{r}\right)^n\sum_{m=0}^{n}\left(\bar{C}_{nm}\cos m\lambda + \bar{S}_{nm}\sin m\lambda\right)\bar{P}_{nm}(\cos\theta) \tag{6}$$

The higher the order of the expansion of the spherical harmonic model of the Earth's gravity field, the higher the resolution, and the more the high frequency portion of the gravity signal is reflected. The EGM2008 model developed by NGS and the EIGEN-6C4 developed by Bolzmann GFZ in Germany are two typical super-high-order gravity models. EGM2008 is the first successful application of the ultra-high-order global gravity model, the model mainly uses GRACE satellite data, terrain data, satellite altimetry data and ground gravity observation data fusion of global gravity model. The accuracy of EGM2008 model is evaluated by many international research institutions. The results show that the accuracy of the vertical deviation measurement is about 2 ~ 3 "(RMS), and the accuracy of this model is about 2 ~ 3" In North America, the accuracy is even higher, with large residuals in areas where gravity data is scarce, such as Africa, Asia, certain parts of South America, and the coastal waters of Greenland, Figure 1 and Figure 2, respectively The east and north components of the gravity disturbance in the east longitude 100 ° to the west longitude 120 ° and the 30 ° north and south latitude are calculated using the EGM 2008 model. Table 1 gives the relevant statistical results.

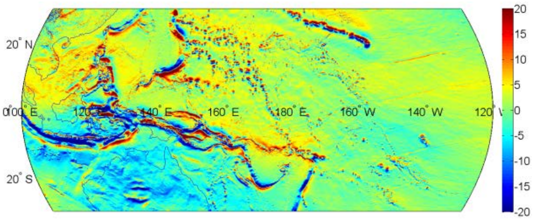

Figure 1. Pacific, Indian Ocean and Neighborhood 2.5 '× 2.5' Spatial Vertical Deviation Easting Component

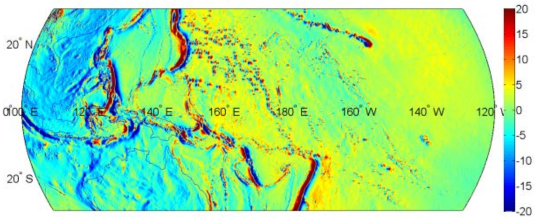

Figure 2. The vertical offset of the 2.5 'x 2.5' space in the Pacific, Indian Ocean, and neighborhood

Table 1. Pacific Ocean, Indian Ocean and Neighborhood 2.5 '× 2.5' Spatial Vertical Deviation Statistical Results ('')

	average value	Root mean square value	Standard deviation
ξ	3.34	36.20	36.04
η	-0.24	5.89	5.86

It can be seen that in most of the oceans the vertical deviation is less than 10 ", but there are also many areas more than 20", especially in some areas where islands and reefs are denser. This will have a significant impact on high-precision marine inertial measurement systems.

Accuracy Analysis of Gravity Disturbance on Inertial Navigation System

The platform-type northbound inertia error equation considering the gravity perturbation is given by:

$$\begin{cases} \delta\dot{v}_x = \dfrac{v_y^t}{R}\tan\varphi\cdot\delta\dot{v}_x + \left(2\omega_{ie}\sin\varphi + \dfrac{v_x^t}{R}\tan\varphi\right)\delta v_y \\ +\left(2\omega_{ie}v_y^t\cos\varphi + \dfrac{v_x^t v_y^t}{R}\sec^2\varphi\right)\delta\varphi - \phi_y g_0 + \Delta A_x - \Delta g_x \\ \delta\dot{v}_y = -\left(2\omega_{ie}\sin\varphi + \dfrac{v_x^t}{R}\tan\varphi\right)\delta v_x \\ -\left(2\omega_{ie}v_x^t\cos\varphi + \dfrac{v_x^t v_x^t}{R}\sec^2\varphi\right)\delta\varphi + \phi_x g_0 + \Delta A_y - \Delta g_y \\ \dot{\phi}_x = -\dfrac{\delta v_y}{R} + \omega_{ie}\sin\varphi\cdot\phi_y - \omega_{ie}\cos\varphi\cdot\phi_x \\ \dot{\phi}_y = \dfrac{\delta v_x}{R} - \omega_{ie}\sin\varphi\cdot\phi_y - \omega_{ie}\cos\varphi\cdot\phi_x \\ \dot{\phi}_z = \dfrac{\tan\varphi}{R}\delta v_x + \omega_{ie}\cos\varphi\cdot\delta\varphi + \omega_{ie}\cos\varphi\cdot\phi_x \\ \delta\dot{\varphi} = \dfrac{\delta v_y}{R} \\ \delta\dot{\lambda} = \dfrac{1}{R}\sec\varphi\cdot\delta v_x \end{cases} \quad (7)$$

Using Matlab simulation, we can obtain the angle variation curve of the attitude error of the system only considering the vertical deviation, as shown in Fig.3 and Fig.4. The latitude of the simulation is 25 ° north latitude. It can be seen that the vertical deviation of 15 "causes a large system attitude error, which exceeds the horizontal attitude angle accuracy requirement and must be compensated.

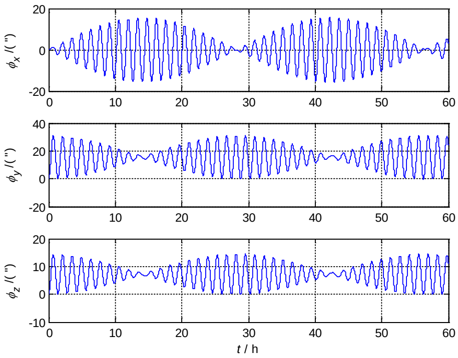

Figure 3. Effect of 15 "east-perpendicular deviation on inertial attitude error

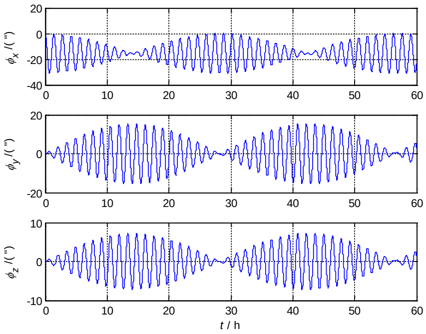

Figure 4. Effect of 15 "north-perpendicular deviation on INS attitude error

Discussion on Gravity Disturbance Compensation Method

In summary, if the gravity anomaly component value of each region is known, the accelerometer can be compensated for the gravity anomaly component in the mechanical arrangement of the inertial navigation system. Taking the north direction inertial navigation as an example, the original velocity control equation is:

$$\begin{cases} \dot{v}_x^c = A_x + \left(2\omega_{ie}\sin\varphi_c + \dfrac{v_x^t}{R_N}\tan\varphi\right)v_y^c & v_x^c(0) = v_{x0} \\ \dot{v}_y^c = A_y - \left(2\omega_{ie}\sin\varphi_c + \dfrac{v_x^t}{R_N}\tan\varphi\right)v_x^c & v_y^c(0) = v_{y0} \end{cases} \tag{8}$$

To the following equation:

$$\begin{cases} \dot{v}_x^c = A_x + \left(2\omega_{ie}\sin\varphi_c + \dfrac{v_x^t}{R_N}\tan\varphi\right)v_y^c + \Delta g_x & v_x^c(0) = v_{x0} \\ \dot{v}_y^c = A_y - \left(2\omega_{ie}\sin\varphi_c + \dfrac{v_x^t}{R_N}\tan\varphi\right)v_x^c + \Delta g_y & v_y^c(0) = v_{y0} \end{cases} \tag{9}$$

Under normal circumstances, the measurement vessel to perform the task routes are predetermined, and for the general uniform linear motion. Therefore, for the special application of the measuring ship, the vertical deviation of the mission area can be forecasted in advance by using the high precision gravity disturbance library, and the related parameters binding work can be done well.

Summary

In this paper, the inertia navigation system of measuring ship platform is analyzed, and the distribution of gravity vertical deviation in the mission sea area is analyzed. The effect of gravity disturbance error on inertial navigation measurement accuracy is simulated and analyzed. Finally, a scheme for the correction of gravity perturbation in platform inertial mechanics arrangement is proposed. The next step will be the proposed method of experimental data analysis and experimental verification.

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