A Marine Gravimeter Based On Precise Single-point Positioning Technology In Pacific Ocean

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Abstract. Marine gravity measurement is one of the methods of marine geophysical measurement. The marine test used the SGA-WZ02 gravity meter independently developed by the National University of Defence Technology (NUDT), about 60 days of maritime tests were conducted in the Pacific Ocean from July to September 2019. The purpose of the test is to evaluate the feasibility of this gravimeter for marine gravity measurement and the accuracy of data processing using GNSS precision point positioning technology (PPP) in the later stage. The test area is located in a strait in the Pacific Ocean. The total area of the test area is about 2840 km² and the total distance is about 1074km. Among them, 7 repeat lines were measured, each distance was about 14.5km, and the ship speed was about 27.78km/h. In this paper, GNSS precision single-point positioning technology is used to evaluate the quality of the data of 7 repeated lines. After 100s low-pass filtering, the standard deviation of the accuracy within the SGA-WZ02 gravity meter is 0.56mGal, and the median error is 0.60mGal. The test results show that the SGA-WZ02 strapdown gravimeter can be used for the measurement of marine gravity field. The data processing algorithm based on precise single-point positioning technology meets the accuracy requirements of gravity measurement.

1. Introduction

Ocean gravity measurement is one of the methods of marine geophysical measurement. With sufficient ocean gravity data, a more accurate shape of the global geoid can be obtained. At present, several foreign countries are in a leading position in marine gravity measurement technology, such as the L&R III gravity meter developed by LaCoste & Romberg in the United States, the GT-2M marine gravity meter in Russia. China's marine gravity measurement has developed to the stage of shipborne gravity test. In recent years, the National University of Defence Technology (NUDT) have used their own gravity instruments doing the marine gravity experiment. Section 2 of this article introduces the structure of the SGA-WZ02 gravimeter, Section 3 introduces the principle of marine gravity measurement and GNSS precision single-point positioning technology, Section 4 describes the marine test process, and Section 5 analyzes the test results and draws conclusions.
2. Structure of SGA-WZ02 Gravimeter

Gravity measurement system based on strapdown inertial navigation system (SINS), using a mathematical platform instead of a physical platform, eliminating the physical platform structure, which results in a simpler structure, smaller size, lighter weight, simple operation, and unmanned Operation to further perform gravity vector measurement. The SGA-WZ02 strapdown gravimeter independently developed by the National University of Defence Technology is shown in Figure 1.

The SGA-WZ02 gravity meter is mainly composed of two parts, from top to bottom, a control box and a sensor box. The control box is mainly composed of data acquisition system, monitoring display system and power supply, which is responsible for power supply management and data acquisition of the gravity measurement system; The sensor box is mainly composed of three navigation-level laser gyroscopes, three high-precision quartz flexible accelerometers, temperature control system and GPS system, etc., and is responsible for high-precision ratio measurement and attitude measurement.

3. Principle

3.1. Principle of The Marine Gravimeter

At present, the principle commonly used for gravity measurement is the direct difference method (Figure 2). Because of the long distance of the ocean test, it would be very error to set up the base station separately and carry out the carrier phase differential GPS. The difference operation obtains the required gravity field information.

The important formulas of the direct difference method are listed below:

According to Newton's second law, the specific force equation in the local geographic coordinate system can be derived as:

\[ \ddot{v}_n = C_{bn} f^b - (2\omega_\theta + \omega_\phi) \times \dot{v}_n + g^b \]  

(1)

Where \( \ddot{v}_n \) is the acceleration of the carrier, \( \dot{v}_n \) is the velocity of the carrier, \( f^b \) is the specific force measurement of the accelerometer, \( C_{bn} \) is the directional cosine matrix between the body coordinate system \( b \) and the local geographic coordinate system \( n \), and \( \omega_\theta \) is the projection of the earth's rotation angular velocity in the local geographic coordinate system \( n \), and \( \omega_\phi \) is the projection of the angular velocity of the local geographic coordinate system \( n \) relative to the earth coordinate system \( e \) in the \( n \) system, \( [b \times] \) is an obliquely symmetric matrix of vector \( b \), \( g^b \) is the actual gravity vector.

\[ g^n = g^b + \delta g^b \]  

(2)

Where \( \gamma^n \) is normal gravity, \( \delta g^b \) is the requested gravity disturbance vector, which is the gravity information we ultimately need.

3.2. Principle of GNSS Precise Single-Point Positioning Technology

GNSS precise point positioning (PPP) refers to the use of carrier phase and coded pseudorange observations of a GNSS receiver, using high-precision satellite orbit and clock offset products, achieving high-precision positioning by carefully considering the influence of errors related to
satellites, signal propagation paths, and receivers on positioning through model correction or parameter estimation. PPP generally uses a non-difference observation model, which can accurately estimate the absolute coordinates of the station under the ITRF framework, the receiver clock difference, the absolute zenith tropospheric delay and its horizontal gradient, and the ionospheric delay on the signal propagation path.

4. Experiments
From July to September 2019, the SGA-WZ02 gravity meter independently developed by NUDT carried a certain type of measurement ship. Starting from Zhoushan, Zhejiang, a 60-day marine test was conducted in the Pacific. The equipment installation and working status are shown in Figure 3. The 7 repeat lines are shown in Figure 4. Longitude and latitude have been blurred.

The gravimeter mounting plate is fixed to the floor with 3M glue, and the gravimeter is fixed to the corresponding position of the mounting plate with screws. The power supply part of the gravimeter is a 24V DC power supply, connected in series with a 6-axis 5200mAh UPS power supply, and then connected to the power supply port of the gravimeter through the xt60 connector. Once the gravimeter is turned on, it will cause incomplete test data if the power is turned off. During the test, the ship's hull is generally not powered off. Even if the power is off, the 5200mAH UPS power supply can ensure a stable power supply voltage for 30 minutes, ensuring that the gravity measurement system works continuously throughout the test.

5. Results and Conclusion
For repeated measurement lines, the internal coincidence accuracy evaluation method can measure the consistency between the single measurement value of the equipment and the average value of multiple repeated the stability of the device itself. The formula is as follows:

\[ e_j = \pm \sqrt{\frac{\sum_{i=1}^{n} \delta_{ij}^{2}}{n}}, (j = 1, 2, \ldots, m) \]  

(3)

where:
\( \delta_{ij} \) is the internal coincidence accuracy of the \( j \) repeated line, \( \delta_{ij} \) is the difference between the observation value of the \( i \) measurement point on the \( j \) repeated line and the average value of the observation values of each repeated line at that point, \( n \) is the total number of observation points in the common segment of the repeating line, \( m \) is the total number of repeated lines.

Gravity extraction was performed through low-pass filters of 100s, 200s, and 300s. The test results are as follows, Longitude and latitude have been blurred.

300s low-pass filtering:

|   | Min  | Max  | Mean | Std  | Rms  | Point |
|---|------|------|------|------|------|-------|
| ML6 | -0.25 | 0.94 | 0.10 | 0.20 | 0.22 | 405   |
From the above results, it can be seen that after 100s low-pass filtering, the standard deviation is 0.56 mGal, and the median error is 0.60 mGal; after 300s low-pass filtering, the standard deviation is 0.20 mGal and the median error is 0.31 mGal, which means that the test results are at the same level of accuracy as the current mainstream marine gravimeters. This test shows that the SGA-WZ02 strapdown gravimeter can be used for marine gravity measurement, and GNSS precision single-point positioning technology can be used for post hoc data analysis of this gravimeter.

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