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Application of precise point positioning technology in airborne gravity measurement

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Abstract: The precise point positioning (PPP) technology is applied to an airborne gravity survey. By analyzing the advantages and disadvantages of several velocity and acceleration measurement methods and in combination with an actual marine gravity survey, the position difference method is confirmed to be a useful survey method for velocity and acceleration. Finally, the practicability of using PPP in airborne marine gravity survey is verified by measured data.

Key words: precise point positioning; gravity; velocity; acceleration; application

1 Introduction

Developments in marine survey technology have resulted in a gradual shift in measurement mode from the surface to air. Due to slow velocity, traditional shipborne gravity measurement has low work efficiency. Moreover, it can be easily influenced by obstacles such as reefs or oil field apparatus, and the working area is limited. However, airborne gravity measurement has higher work efficiency, the working area is not limited, and it meets the demand of rapid gravity measurement. Airborne gravity measurement is conducted on an aircraft carrier using the airborne gravity measurement system to measure near-space gravity acceleration. To determine a location with high precision, velocity and acceleration of the aircraft is used for airborne gravity measurement. Determination of the correct position and velocity reveals the space-time data of the plane. In addition, these factors are necessary for computing eotvos, horizontal acceleration, and spatial corrections. Accurate determination of the vertical acceleration of the aircraft is crucial for separating the vertical disturbing acceleration and gravity signal. Thus, accurate determination of the aircraft vertical disturbing acceleration strongly influences that of the gravity anomaly[1-5].

With the expansion range of ocean measurement and because of the difficulty in building a base station, traditional differential GS technology has been unable to meet the demands of airborne gravity measurement. However, precise point positioning (PPP) can satisfy the demands of airborne gravity measurement without the use of reference stations and can provide position, velocity, and acceleration information of high accuracy for airborne gravity measurement.

2 Selection of velocity and acceleration measurement method

Many methods are used to measure velocity and acceleration by GPS such as position difference, Doppler observation value, and carrier phase difference. A relation exists among these three methods because they are all based on the definition of the velocity formula. However, differences in calculation procedures and observation values lead to different degree of hypotheses approximation for each method; thus, the accuracy of the

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velocity determined by each method also differs[6-12].

2.1 Comparison of velocity, acceleration measurement methods

In this section, the three aforementioned types of velocity will be compared and analyzed according to the degree of difficulty in data processing, accuracy of velocity, and sampling interval.

(1) Degree of difficulty. It is difficult to accurately determine the position differential in data processing. However, if the high accuracy position has been obtained in actual measurement, velocity calculation based on position difference becomes simple.

(2) Velocity accuracy. When the motion of the carrier is uniform, the position difference and carrier phase difference methods can be used to achieve velocity with high precision. If the carrier velocity changes significantly, the precision of the velocity measurement in the Doppler frequency shift method is higher than that in the position difference and carrier phase difference methods.

(3) Sampling interval. The position difference and carrier phase difference methods require a small sampling interval. Conversely, the Doppler frequency shift method has no requirements for the sampling interval.

The above comparison and analysis reveal that combined with practical application of the PPP technology used in sea gravity measurement, the position difference method is suitable for measuring carrier velocity and acceleration.

2.2 Using the position difference method to calculate velocity

The position difference method is a main velocity measurement technique commonly used at home and abroad in marine gravity measurement. In this method, accurate position information of the carrier and the appropriate differential filter are required. The basic principle is given below.

Differencing by the position vector of epoch t and epoch $t+h$, the velocity of epoch t can be calculated as follows:

$$\dot{\boldsymbol{r}}=\frac{1}{h}(\boldsymbol{r}_2-\boldsymbol{r}_1) \tag{1}$$

where h is the sampling interval. Therefore, formula (1) is determined by the velocity of the carrier at time h of the average velocity. If h is close to zero, the average velocity is the instantaneous velocity. The smallest sampling interval yields the most accurate velocity information.

2.3 Using position difference to calculate acceleration

In marine airborne gravity measurement, the total acceleration measured by gravimeter is the vertical acceleration. A precision of 2-3 mGal is needed for determining the disturbing acceleration.

By using epochs t and $t+h$, the position vectors, $\boldsymbol{r}_1$ and $\boldsymbol{r}_2$, a second differential, using appropriate filter, epoch t, carrier acceleration can be determined by t.

$$\ddot{\boldsymbol{r}}=\frac{1}{h^2}(\boldsymbol{r}_2-\boldsymbol{r}_1)(\dot{\boldsymbol{r}}_1-\dot{\boldsymbol{r}}_2) \tag{2}$$

where h is the sampling interval.

3 Analysis from actual example

To analyze the effect of the application of PPP in marine airborne gravity measurement, actual data measured in an airborne gravity ocean test were used in the calculation. Velocity and acceleration were calculated on the basis of position with primary and secondary derivatives. The result calculated by PPP and differential positioning were compared. Two types of GPS receiver were used in the measurement process. The first was placed at the coast as the base station, and the second was placed in the plane. The two receivers recorded synchronous data with a data sampling interval of 1 s, and the aircraft velocity was maintained at approximately 400 km/h for uniform flight. Variations of the track line and altitude of the aircraft are shown in figures 1 and 2, respectively.

3.1 Analysis of the positioning result

A comparison of the results calculated by PPP and differential positioning revealed a difference curve, as shown in figure 3. The statistical results of the difference are shown in table 1.

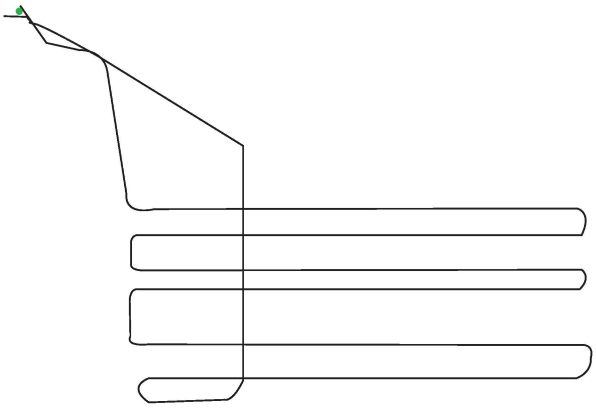

Figure 1 Track line of the aircraft

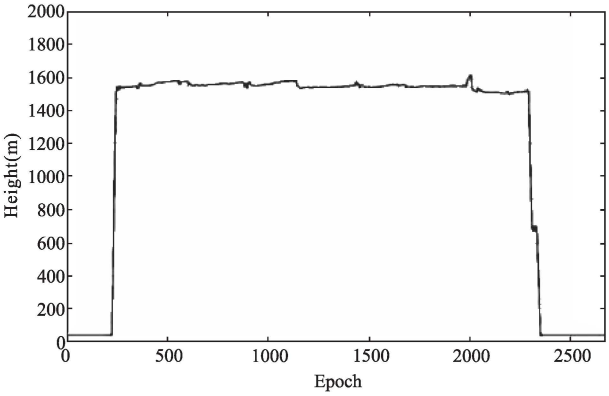

Figure 2 Variation of the aircraft's altitude

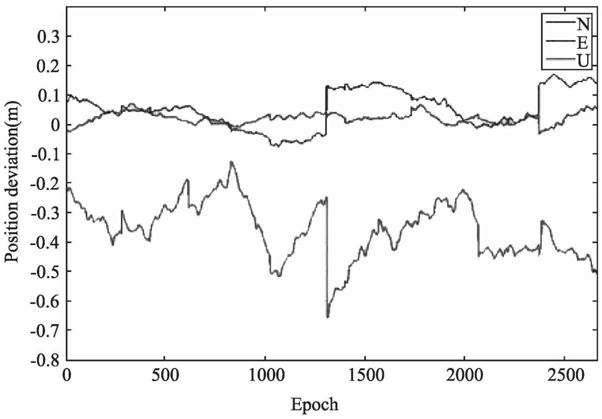

Figure 3 Airborne precise point positioning accuracy of calculation

Figure 3 and table 1 show that compared with differential positioning calculation results, the standard deviation of PPP in the latitude, longitude, and height directions were 0.0644 m, 0.0197 m, and 0.0943 m, respectively. Some systematic differences were apparent in the two types of solution results, which may be due to the difference in the positioning models.

Table 1 Differences in statistical results (unit: m)

	Max	Min	Mean	Std
N	0.1683	−0.0774	0.0540	0.0644
E	0.0700	−0.0340	0.0197	0.0197
U	−0.1254	−0.6624	−0.3575	0.0943

3.2 Analysis of the velocity results

After filtering, a comparison was made of the derivative position used in the numerical solution with PPP using the aircraft velocity and difference solution of aircraft velocity. The obtained difference curve is shown in figure 4, and differences in statistical results are shown in table 2.

The results indicate that compared with differential positioning, the velocity calculation precision of PPP was the highest. The precision in the horizontal direction of the velocity was higher than that in the vertical direction.

3.3 Analysis of the acceleration results

By taking the derivative of position twice, after filtering, and comparing the aircraft's acceleration calculated by PPP and differential positioning, a difference curve was obtained as shown in figure 5; the statistical results of the acceleration difference are shown in table 3.

Figure 5 and table 3 show that the acceleration results calculated by PPP and differential positioning were fairly similar. The error in both was less than 2 mGal, and the error of standard deviation in the north-south (N), east-west (E), and overall statistics (U) were 0.1359 mGal, 0.1349 mGal, and 0.3803 mGal, respectively.

3.4 Analysis of gravity measurements

The PPP technology solution based on the gravity results and differential positioning technology solution of gravity were compared; the obtained statistical results are shown in tables 4 and 5, respectively.

The results show that the cross point discrepancies calculated by PPP and differential positioning were equivalent. The average value of the gravity comparison result was 0.07 mGal, and the standard deviation was 0.31 mGal.

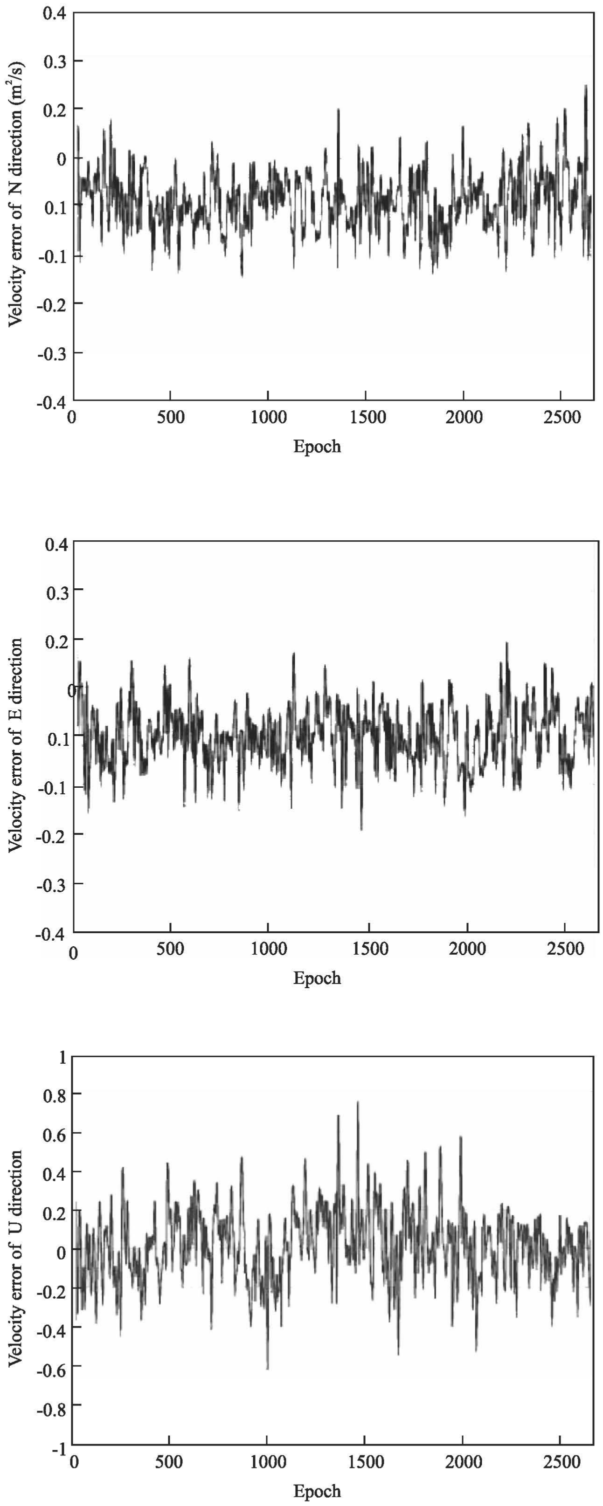

Figure 4 Velocity error results

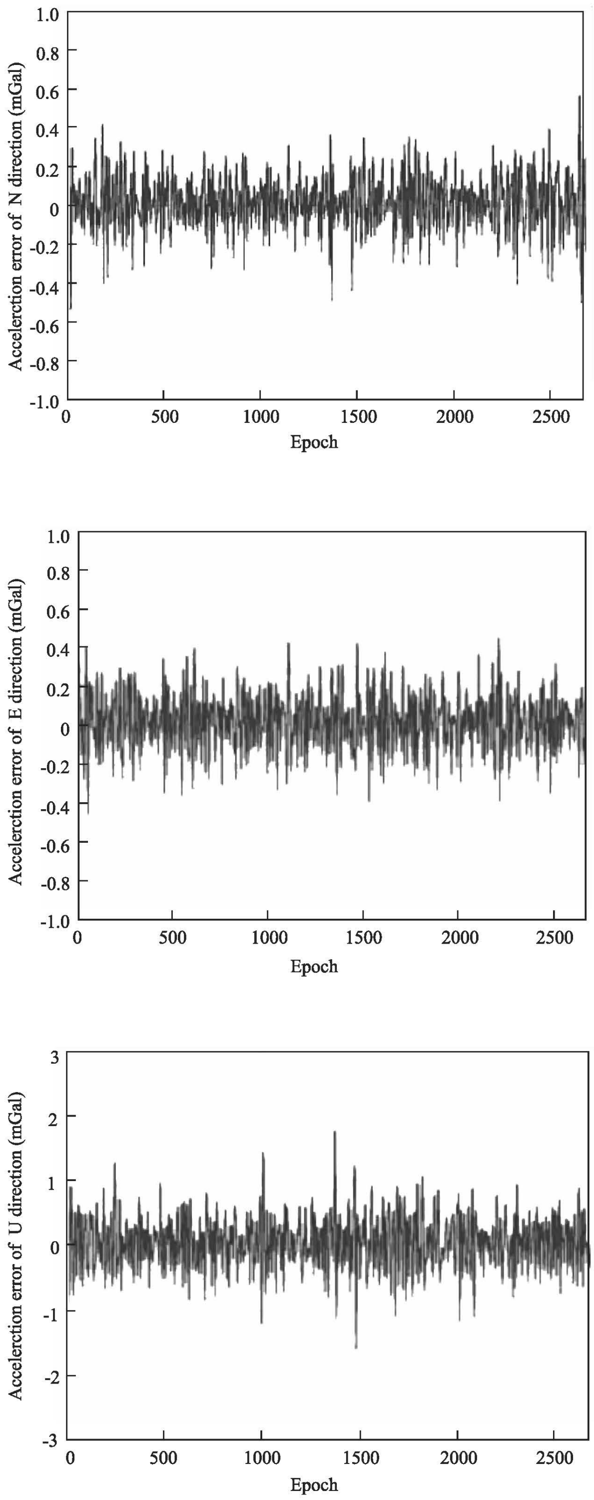

Figure 5 Acceleration error results

Table 2 Velocity error statistics (unit: mm/s)

	Max	Min	Mean	Std
N	0.2568	−0.1488	−0.0076	0.0610
E	0.1958	−0.1961	0.0056	0.0606
U	0.7595	−0.6234	−0.0020	0.1828

Table 3 Comparison of statistical acceleration results (unit: mGal)

	Max	Min	Mean	Std
N	0.5610	−0.5355	−0.0012	0.1359
E	0.4456	−0.4579	0.0001	0.1349
U	1.7542	−1.6037	−0.0010	0.3803

Table 4 Crossover differences in statistical results (unit: mGal)

	Max	Min	Mean	Std
Based on the differential positioning technology	3.94	−2.38	0.77	2.37
Based on precise point positioning technology	4.35	−2.46	0.78	2.69

Table 5 Comparison of statistical gravity results (unit: mGal)

	Max	Min	Mean	Std
North-South direction	0.69	−1.04	−0.14	0.26
East-West direction	2.40	−2.01	0.11	0.31
Overall statistics	2.40	−2.01	0.07	0.31

4 Conclusion

We researched the application of the precise point positioning (PPP) technology in airborne marine gravity measurement and compared and analyzed the results of position, velocity, acceleration, and gravity calculated by PPP and differential positioning by using measured data. The precision of the results by using both methods was very close. Because a base station cannot be positioned in some areas, differential positioning cannot be used in all cases. Therefore, PPP is better suited for marine airborne gravity measurement.

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