Method of Anomaly Measurement of GPS Elevation in Sea Area

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Abstract. In view of the problem of dynamic GPS elevation anomaly control measurement, the fitting model is optimized. Under the dynamic condition of the sea, the differential GPS receiver is used to design the measurement network according to the certain route. At the same time, the high range fitting method is used to select the GPS elevation linear fitting model and the barometer level height measurement for normal high contrast compensation measurement. The method is used to preprocess the collected data in real time, and the real time analysis and compensation of the barometer leveling data for the fitting output results can effectively realize the regional GPS elevation measurement under the sea dynamic condition.

1. Introduction

GPS is widely used in precision engineering survey for its advantages of high speed, high accuracy and simplicity. The common GPS elevation is the height of the earth based on the WGS-84 ellipsoid, and the actual elevation is determined through leveling as the datum of the geoid. Because the height datum of the two is different, the height of the earth measured by GPS can not be directly used for engineering measurement and production. It is necessary to find elevation anomalies by using the known points of the height of the earth and the normal height of the known point, and then find out the elevation anomaly of the known point. The height anomaly of other unknown points will replace those of leveling under or unable to pass through the area [1].

At present, the general static GPS relative positioning can achieve the precision requirements of the engineering measurement. However, the accuracy of the dynamic elevation control measurement has not been identified, especially in the offshore area. On the basis of experimental research and practice, puts forward a method to obtain high precision height difference by using GPS to measure elevation technique, barometer leveling and curve fitting on the basis of experimental research and practice.

2. GPS Elevation System

The difference between the normal geoid and the ellipsoid of the datum of the ground height is usually called elevation.

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**Diagram**

- Geodetic height
- Normal height
- Orthometric height
- Earth's surface
- Quasi geoid
- Reference ellipsoid
- P
- P'
- P''
- N
- ξ

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The elevation system based on reference ellipsoid is called the earth height elevation system. The distance $H$ from the earth's point along the ellipsoidal normal to the ellipsoid is called the ground elevation of the ground point. As shown in Figure 1, the height of the ground point is $PP'$. The geodetic height $H$ of the ground point relative to the WGS-84 ellipsoid is measured by GPS. The elevation system, which takes the geodetic level as the elevation datum, is called a positive elevation system, and the distance from the vertical line to the geoid on the ground is called the positive elevation of the point $\eta$.

The fact that the vertical height is not accurately obtained, have set up the normal height and elevation system for the convenience of use. It is defined as:

$$H_r = \frac{1}{r_a} \int_0^{\eta} gdh$$

(1)

The mean value of gravity acceleration along the plumb line to the geoid $\mathcal{G}$ is the ground point. It can not be accurately measured, and can not be derived from the formula, so it is not possible to directly obtain the vertical height. The distance between the geoid and the ellipsoid is called the geoid difference. The formula for calculating normal gravity on an ellipsoid is:

$$r_a = r_e \left(1 + \beta_1 \sin^2 \phi - \beta_2 \sin^2 2\phi\right)$$

(2)

It is the normal gravity value on the equatorial ellipsoid; $r_e$ is coefficient related to the ellipsoidal definition; $\phi$ is astronomical latitude of the ground point. The current values in our country are as follows:

$$r_e = 978.030, \quad \beta_1 = 0.005302, \quad \beta_2 = 0.000007$$

It can be seen that the normal high system is a height system based on quasi geoid. It can be accurately determined and widely used in practical engineering.

3. Elevation Anomaly and GPS Height Fitting Principle

It is very difficult to measure the abnormal height accurately. One GPS single point positioning error is large; two is the lack of high precision GPS datum point in the measurement area, the high precision earth height is difficult to get after the GPS network adjustment, so it is difficult to use the model to accurately calculate the normal height of each GPS point.

3.1. Elevation Anomaly

The difference between the normal high base level quasi geoid and the datum ellipsoid of geodetic height is called Elevation anomaly, usually expressed in letters $\zeta$. That is, in Figure1, the expression is $PP'$:

$$\zeta = H - H_r$$

(3)

3.2. GPS Height Fitting Principle

GPS height fitting is based on the principle that the height anomaly has certain geometric correlation in a small area. By using mathematical method, the numerical model of the height anomaly distribution in the survey area is established according to the height anomaly value of GPS point and leveling coincidence point and the coordinates of the points. The coefficient of the fitting model is calculated and the measurement area is solved. The height anomaly value of other points is then used to solve the process of normal height and normal height [1].
4. GPS Elevation Fitting Method and Implementation

The accuracy of the normal height obtained by the GPS depends on the correctness of the elevation anomaly model of the GPS level [2]. On the sea surface, considering that the GPS elevation measurement in the sea area is not restricted by the point position, it is easy to set the GPS point into a continuous network in the region. The surface fitting and curve fitting are selected, but the measurement area is too small, it is easy to be affected by the surge change. At the same time, the economic factors of the plane survey network, the long time measurement area pressure change, the high precision of the pressure level are not well controlled, so the curve fitting method is adopted.

4.1. Curve Fitting Model

The approximate geoid is approximated to the plane by curve fitting. The first three items of the spatial surface function can be selected, which requires at least three common points. At this time, the fitting of the geoid fitting plane can be expressed as [3]:

\[
f(x_i, y_i) = a_0 + a_1 x_i + a_2 y_i
\]

In this way, at least four public points, then the expression of formula 4-1 fitting becomes:

\[
f(x_i, y_i) = a_0 + a_1 x_i + a_2 y_i + a_3 x_i^2 + a_4 x_i y_i + a_5 y_i^2
\]

Taking the six parameter fitting as an example, the fitting coefficient \( \zeta_i = f(x_i, y_i) + \epsilon_i \) is solved by the least square method in the surface function, that is \( \zeta_i \approx f(x_i, y_i) \), as long as the fitting coefficient is obtained, the relation function formula between the height anomaly zeta and the coordinate can be determined.

\[
f(x_i, y_i) = a_0 + a_1 x_i + a_2 y_i + a_3 x_i^2 + a_4 x_i y_i + a_5 y_i^2
\]

The Elevation anomaly on this point is calculated by the normal height measured by the geodetic height measured by GPS in the public point and the normal height measured by barometer leveling. If there are common m common points in this point, the M equation can be listed by formula 6.

\[
\begin{align*}
\zeta_1 &= a_0 + a_1 x_1 + a_2 y_1 + a_3 x_1^2 + a_4 x_1 y_1 + a_5 y_1^2 \\
\zeta_2 &= a_0 + a_1 x_2 + a_2 y_2 + a_3 x_2^2 + a_4 x_2 y_2 + a_5 y_2^2 \\
&\vdots \\
\zeta_m &= a_0 + a_1 x_m + a_2 y_m + a_3 x_m^2 + a_4 x_m y_m + a_5 y_m^2 \\
\end{align*}
\]

The above formulas are written in the form of linear equations \( V = Ax + L \). Among them:

\[
A = \begin{bmatrix}
1 & x_1 & y_1 & x_1^2 & x_1 y_1 & y_1^2 \\
1 & x_2 & y_2 & x_2^2 & x_2 y_2 & y_2^2 \\
& \vdots & \vdots & \vdots & \vdots & \vdots \\
1 & x_m & y_m & x_m^2 & x_m y_m & y_m^2
\end{bmatrix}
\]

\[
x = \begin{bmatrix}
a_0 \\
a_1 \\
& \vdots \\
a_5 \\
\end{bmatrix}
\]

\[
V = \begin{bmatrix}
\zeta_1 \\
\zeta_2 \\
& \vdots \\
\zeta_m
\end{bmatrix}
\]

\[
A = \left( A^T P A \right)^{-1} A^T P L
\]

For warrants, \( P \) is can be determined according to the height of the air pressure and the accuracy of the earth height measured by GPS.

4.2. Fitting Process

The specific engineering flow chart as follows:
Coordinate data preprocessing (organizing data in specified format, transforming data into matrix form and centralization, etc.)

Using the least square method to solve the coefficient of fitting model

Substituting numerical value for the fitting elevation anomaly model \( \zeta \)

Comparing the height anomaly and finding the residual

Find out the unmeasured point

Internal accuracy

External accuracy

Comparing, Determine the model

Leveling Height

Real time revision, Optimized results \( \zeta \)

Figure 2. GPS height fitting and barometric leveling flow chart

After finding the fitting coefficient, the function relation between the height anomaly and the coordinate is determined, and the coordinate value can be replaced in the expression in MATLAB, and the elevation anomaly value of the unmeasured point [5] is solved, and the fitting coefficient is used to inverse the height anomaly value of the experimental data, and the elevation anomaly value of the experimental data is compared. The residual value is obtained and the internal precision is evaluated and analyzed. At the same time, the fitting elevation anomaly value of the unmeasured point of the sea area is evaluated as the external precision. The fitting effect of the model is evaluated as a whole. Finally, the optimal fitting model is selected by comparing the residuals of the single point and the internal and external accuracy of the fitting.

5. Results

In this experiment, the GPS receiver adopts the Star Station differential mode, the horizontal position accuracy is better than 0.3m (2dRMS), the elevation accuracy is better than 0.5m, and the speed accuracy is better than 0.03m/s. By analyzing the fitting data obtained from the fitting models, the six parameter fitting method has reached millimeter level in precision, and it has high fitting precision. It can be used for general engineering measurement under the smooth conditions of the sea surface.
Figure 3. Horizontal position change of GPS measurement point at sea

Figure 4. Contour map of ground speed change at GPS measurement point at sea (m/s)

In the case of the range of sea surface, the elevation error is measured by a barometer in the continuous measurement of the elevation anomaly on the navigation route by the combination of GPS equipment and barometer. The height error of the reclosing number is measured by the barometer. The trajectory distribution is designed according to Figure 3, but the error measurement is also more complex due to the sea surge ocean current factors. Consider the change of ground speed at the measuring point, as shown in Figure 4. At the same time, if the whole quasi geoid is to be synthesized from plane or six parameter surfaces, it will not be ideal. At this time, 4.2 mobile polynomial method can be adopted.

As shown in Figure 5 the dynamic fitting accuracy is less than 10m within 6000 seconds by continuous reference correction. From figure 6, it is found that the accuracy of the fitting model can be seen on the actual measurement distribution of GPS.
Figure 6. GPS actual measurement and reference point elevation contrast

The accuracy of the first 3500 points is low, and the height error of the fitting and barometer is corrected. The accuracy of the latter 3500 points indicates that the fitting model is in line with the variation law of the elevation anomaly in the fitting area.

6. Conclusion

For the comparison of various models and the identification of environmental conditions, the fitting model suitable for a certain area is finally chosen. According to the characteristics of the sea environment, the fitting model is established by linear fitting. At the same time, in the process of measurement, the barometer level point is used for measurement and correction in real time. In continuous correction, GPS is proposed. To a large extent, the height accuracy depends on the uniformity of height anomaly in the survey area.

In addition, the number of GPS reference level points will also affect the fitting results. If the number is too small and the distribution is uneven, it is not enough to accurately characterize the trend of the dynamic environmental level of the sea. The polynomial curve fitting can be used when the GPS point is set in the sea at sea. The more precision of fitting times is not necessarily higher, but the times of fitting must be combined with the actual needs.

7. References

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