A whitening filter-based LAMBDA group searching method

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Abstract. When using GPS carrier phase differential technique for dynamic positioning, the traditional LAMBDA (Least-squares AMBiguity Decorrelation Adjustment) has shortcomings in the existence of iteration, long solving time and large amount of calculation for decorrelation processing. Based on the rapid ambiguity resolution method, combined with feature of Whitening Filter algorithm, a LAMBDA group searching method, based on the Whitening Filter, is proposed. Simulation results show that the method reduces the required time of the ambiguity determining, and effectively improves the calculation efficiency and positioning accuracy.

1 Introduction

The integer ambiguity is always a difficulty in GPS dynamic positioning. In recent years, there are lots of related algorithms about the integer ambiguity, such as AFM (Ambiguity Function Method), FARA (Fast Ambiguity Resolution Algorithm) and LAMBDA (Least-squares AMBiguity Decorrelation Adjustment), in which LAMBDA is recognized as a good algorithm. But LAMBDA algorithm has some shortcomings in decorrelating relevance, and if there is lots of observed data, the model will be relatively complex and searching space will be larger, so the solution will become more difficult.

Based on these understandings, an improved method for solving integer ambiguity is proposed. Using whitening-algorithm to decorrelate the ambiguities and their variance-covariance, then the processing results obtain the optimal ambiguity vector through the LAMBDA group search method, which can effectively improve the computational efficiency and positioning accuracy.

2 The basic principle of traditional LAMBDA method

The double difference equation is:

$$Y = AX + BN + e \tag{1}$$

Where Y is double difference carrier phase observation vector, A is m×3design matrix, B is m×n design matrix, X, N are determined baseline and ambiguity vector, e is error vector. LAMBDA algorithm usually can be divided into three steps: ambiguity estimation, ambiguity searching and ambiguity recognition.

2.1 Ambiguity estimation

Ambiguity estimation is a floating-point result of observation equations, Floating point of the double difference equation is obtained by ambiguity estimation, commonly used estimation method of Kalman Filter and the least square method. $\hat{X}$ is estimated value, $\hat{N}$ is floating point, $Q_{\hat{N}}$ is covariance matrix.

$$\begin{bmatrix} \hat{X} \\ \hat{N} \end{bmatrix}, \begin{bmatrix} Q_{\hat{X}} & Q_{\hat{X}\hat{N}} \\ Q_{\hat{N}\hat{X}} & Q_{\hat{N}} \end{bmatrix}$$

2.2 Ambiguity searching

The LAMBDA algorithm uses integer transformation method to reduce the effect, which can red-
uce the ambiguity search space. If χ^2 is search scope the ambiguity should satisfy the condition (2):

$$(N - \hat{N})^T Q_{\hat{N}}^{-1} (N - \hat{N}) \le \chi^2 \tag{2}$$

(2) is determined to be a $\hat{N}$ centric multi ellipsoid space, its size is determined by λ^2,The shape is determined by the covariance matrix $Q_{\hat{N}}$. Through the integer transformation (Z transformation), (2) changed to (3).

$$(z - \hat{z})^T L_{\hat{z}}^T D_{\hat{z}} L_{\hat{z}} (z - \hat{z}) \le \chi^2 \tag{3}$$

Where, $\hat{z} = Z^T \hat{N}$, $Q_{\hat{z}}^{-1} = L_{\hat{z}}^T D_{\hat{z}} L_{\hat{z}}$ ($Q_{\hat{z}} = Z^T Q_{\hat{N}} Z$). It can be expressed as formula (4):

$$\sum_{i=1}^{n} d_{z,i} [(z_i - \hat{z}_i) + \sum_{j=i+1}^{n} l_{z,ji} (z_j - \hat{z}_j)]^2 \le \chi^2 \tag{4}$$

In the determination of χ^2, we can get the transform of the integer ambiguity $\tilde{Z}$.

2.3 Ambiguity recognition

The most commonly used methods to confirm the integer ambiguity is Ratio test, the results is the ratio of small variance factor and minimum variance factor. When the ratio of test results is larger than the threshold, the ambiguity is optimal result, otherwise go back to step 2.2 to search again.

Because traditional LAMBDA algorithm needs much iterative times computation in the process of transforming, and much computation, and in the larger data quantity, the search space will become larger, so the time integer ambiguity required becomes longer.

3 A whitening filter-based LAMBDA group searching method

3.1 The decorrelation by whitening filter

When high precision dynamic GPS positioning, the correlation between ambiguity is very strong, leading to an ambiguity floating-point of low precision. So it is necessary to transform the space ambiguity float and the covariance matrix to reduce the correlation between the ambiguity degrees. Whitening filter drop is as follows:

Firstly, the covariance matrix $Q_{\hat{N}}$ is estimated by double difference observation equation is decomposed into (5):

$$Q_{\hat{N}} = U D_1 U^T \tag{5}$$

Where D_1 is a diagonal matrix, U is a lower triangular matrix,

$$U = \begin{bmatrix} 1 & 0 & 0 & \cdots & 0 \\ u_{21} & 1 & 0 & \cdots & 0 \\ u_{31} & u_{32} & 1 & \cdots & 0 \\ \vdots & \vdots & \vdots & \ddots & 0 \\ u_{n1} & u_{n2} & u_{n3} & \cdots & 1 \end{bmatrix} \tag{6}$$

After rounding:

$$U_{\text{int}} = \begin{bmatrix} 1 & 0 & 0 & \cdots & 0 \\ [u_{21}]_{\text{int}} & 1 & 0 & \cdots & 0 \\ [u_{31}]_{\text{int}} & [u_{32}]_{\text{int}} & 1 & \cdots & 0 \\ \vdots & \vdots & \vdots & \ddots & 0 \\ [u_{n1}]_{\text{int}} & [u_{n2}]_{\text{int}} & [u_{n3}]_{\text{int}} & \cdots & 1 \end{bmatrix} \tag{7}$$

Then the D_1 will be changed:

$$Q_{\hat{N}} = U_{\text{int}} Q_{u} U_{\text{int}}^T \tag{8}$$

After transforming the (8), getting a new decorrelation matrix:

$$Q_u = U_{\mathrm{int}}^{-1} Q_{\hat{N}} U_{\mathrm{int}}^{-T} \tag{9}$$

Decomposition of the matrix Q_u:

$$Q_u = L D_2 L^T \tag{10}$$

Where L is lower triangular matrix, once again rounding:

$$Q_u = L_{\mathrm{int}} Q_I L_{\mathrm{int}}^T \tag{11}$$

By iteratively, until the matrix L,U as a unit matrix.

3.2 Group searching

Before the search, according to the ambiguity covariance matrix $\hat{Q}_z$, we can estimate the accuracy of ambiguity. Firstly, the ambiguity is divided into two groups: the smaller variance of ambiguity is principal ambiguity and the larger one is subordinate ambiguity, the smaller variance of ambiguity will be searched.

$$\hat{N}_Z = \begin{bmatrix} E \\ F \end{bmatrix}, \quad \hat{Q}_z = \begin{bmatrix} \hat{Q}_E & \hat{Q}_{EF} \\ \hat{Q}_{FE} & \hat{Q}_F \end{bmatrix} \tag{12}$$

Where E is principal ambiguity, F is subordinate ambiguity. The principal ambiguity mainly through the LAMBDA algorithm to solve the problem, the search space can be defined as:

$$(N_{ZM} - \tilde{N}_{ZM})^T Q_{ZM}^{-1} (N_{ZM} - \tilde{N}_{ZM}) \le \lambda^2 \tag{13}$$

Where N is the integer ambiguity, λ is the confidence coefficient of λ^2 distribution. And the search results by using Ratio method to verify it.

$$Ratio = \frac{R_{2\min}}{R_{\min}} \tag{14}$$

$R_{2\min}$ and $R_{\min}$ respectively the residual two type second minimum and the minimum ambiguity degree. Generally speaking, if Ratio ≥ 2 the minimum ambiguity group is the correct integer ambiguity, else it returns to the search. If the minimum residual has not verified two times by Ratio, then the results will be compared by using filtering search results is correct.

4 Simulation analysis

In order to test the feasibility and the practicability of solving the integer ambiguity with the method of the LAMBDA group searching based on whitening filter, this paper selects the MATLAB7.1 for system simulation environment, the observed data is provided by the document [7], the baseline length of observations is 826.3170m, sampling rate is 1s.

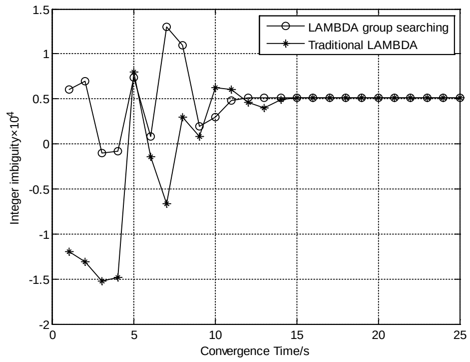

Fig. 1 Convergence time comparison of the traditional LAMBDA algorithm and the LAMBDA group searching method

In Fig. 1, the initial floating-point of the traditional LAMBDA algorithm is -1.20×10^4, and the convergence of the integer ambiguity is 0.51×10^4, so there are quite different. And the floating-point accuracy is not high, the convergence time is long. The initial floating-point of the

LAMBDA group searching based on whitening filter is 0.59×10^4, which is relatively closed to the convergence of the ambiguity, and the convergence time is about 11s. This method is improved too much than the traditional LAMBDA convergence time.

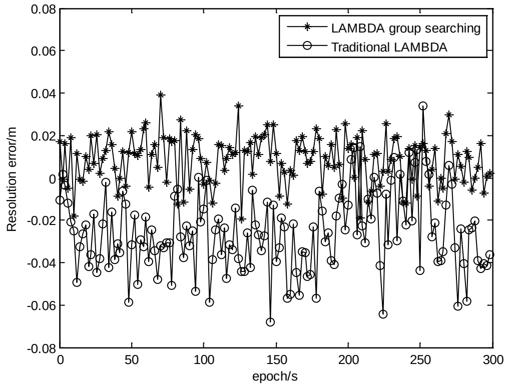

Fig. 2 Calculation error comparison of the traditional LAMBDA algorithm and the LAMBDA group searching method

In Fig.2 we can see that the error of the traditional LAMBDA algorithm is kept in 0.02m and the amplitude fluctuation is large, but the calculating error of the LAMBDA group searching based on whitening filter is kept in about 0.01M and the amplitude fluctuation is very small. By contrast, the solution accuracy of the LAMBDA group searching based on whitening filter is higher than the traditional LAMBDA algorithm.

5 Conclusions

After analyzing and researching on the traditional LAMBDA algorithm, the shortcomings of the traditional LAMBDA algorithm have been analyzed. When the number of data is large, the search space extending has led to solve the problem of the integer ambiguity hard. The LAMBDA algorithm has been improved in this paper. Analyzing experimental data has shown that the LAMBDA group search method based on whitening filtering could effectively improve the accuracy of integer alternation, and would greatly improve the success average and speed of solving the problem. In addition it enhanced the practicability of the complete alternation ambiguity as well.

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