An Improved Extraction Method of Deformation Monitor Information Using Single Epoch

Zongbiao Tian[a], Sitong Guo[b], Hui Liu[c,*], Feng Xiang[b], Zhi Chen[d]

[a] GNSS Research Center, Wuhan University, Wuhan, China - 526859986@qq.com

[b] GNSS Research Center, Wuhan University, Wuhan, China - 251915285@qq.com

[c] GNSS Research Center, Wuhan University, Wuhan, China - loweliu@hotmail.com

[d] Beijing university of post and telecommunications

KEY WORDS: Deformation monitor; Single epoch; Deformation information; Integer ambiguity

ABSTRACT:

GPS technology has been widely used in deformation monitoring, played an important role. Directly extract deformation monitor information from single epoch, and thus realize real-time monitoring of object detection. Combining with the method of integer ambiguity searching using single epoch, puts forward an improved extraction method of deformation monitor information using single epoch on the basis of existing methods without compute the baseline vector, and improved the extraction method. Through some examples, the method was demonstrated.

1. INTRODUCTION

Along with the development of GPS technology of software and hardware, there are more and more wide application in GPS deformation monitoring field, however, cycle slips occur frequently in the deformation monitoring environment, and results in frequent initialization or even wrong ambiguity resolution. It affects the reliability and stability of the deformation monitoring result very much, also brought the difficulty of real-time monitoring. Single epoch ambiguity resolution can avoid cycle slips and becomes the best way to resolve the ambiguity problem in deformation monitoring. So, extraction method of deformation monitor information using single epoch is worth to study, and ambiguity resolution is a key problem, many scholars at home and abroad did a lot of research on single epoch ambiguity resolution.

2. PRINCIPLE

2.1. Theory of extraction

Set up a monitoring network, in the period of monitor observed, the relative to the bench mark time (first period observation), bench mark (p_1) is still, monitoring stations (p_2) occurs deformation. After deformation, the position of p_2 become as p_3, deformation show as d . Now employs deformation observation of monitoring time to get deformation d .In the form of a vector, d can be expressed as:

$$d = \bar{\rho}^i_{P_1} - \bar{\rho}^i_{P_3} - b \quad (1)$$

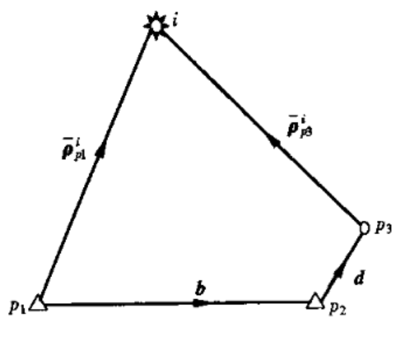

Figure 1: Principle diagram

To acquire deformation of the monitoring station (p_2) in

---
[*] Corresponding author.

the space, compute projection of this type to x, y, z -three coordinate transformation direction. Attend to the carrier phase observation single-difference model and orientation cosine, take point p_2 in the direction of the x axis deformation, for example, we have

$$
\begin{aligned}
d_x &= l_{p_1}^i \bar{\rho}_{P_1}^i - l_{p_3}^i \bar{\rho}_{P_3}^i - x_{p_1,p_2} \\
&= -\lambda l_{p_1}^i N_{p_1,p_3}^1 \\
&+ \left[\begin{array}{l} \left[l_{p_1}^i \left(\lambda \varphi_{p_1}^i - c\delta t_{p_1} + c\delta t^i \right) - l_{p_3}^i \left(\lambda \varphi_{p_3}^i - c\delta t_{p_3} + c\delta t^i \right) \right] \\ + \left(l_{p_1}^i h_{p_1} \sin\theta_{p_1}^i - l_{p_3}^i h_{p_3} \sin\theta_{p_3}^i \right) + \dfrac{l_{p_1}^i \rho_{p_1}^i \dot{\rho}_{p_1}^i - l_{p_3}^i \rho_{p_3}^i \dot{\rho}_{p_3}^i}{c} \\ + \left(l_{p_1}^i \dot{\rho}_{p_1}^i \delta t_{p_1} - l_{p_3}^i \dot{\rho}_{p_3}^i \delta t_{p_3} \right) - x_{p_1,p_2} - l_{p_1}^i \lambda N_{p_1,p_3}^{1,i} - l_{p_1,p_3}^i \lambda N_{p_3}^i \end{array} \right]
\end{aligned} \quad (2)
$$

This type is similar as single-difference model, and the corresponding data processing method as the similar single-difference method. Change the model into error equation form, can calculate the deformation monitoring information solutions, considering the limited length, not detail introduction here.

2.2. Improved method of ambiguity resolution

From (2) can be seen that, ambiguity resolution is a key problem, Use the conditions-short distance of monitoring, its coefficient l_{p_1,p_3}^i (the difference between cosine of benchmark stood and monitoring station in the satellite direction) is small, So according to the carrier phase observation data and pseudo-range observation data can obtain $N_{p_3}^i$. In addition, has put forward various methods to compute ambiguity of phase observation data in dynamic positioning process (also called OTF or AROTF), Such as the least square method, ambiguity function method based on coordinate search, Least squares adjustment differential method by reduce correlation between ambiguity, Cholesky decorrelation decomposition search calculation method, etc. These methods each has their own characteristics , this article puts forward a new ambiguity resolution based on the existing methods to improve extraction method of deformation monitor information using single epoch.

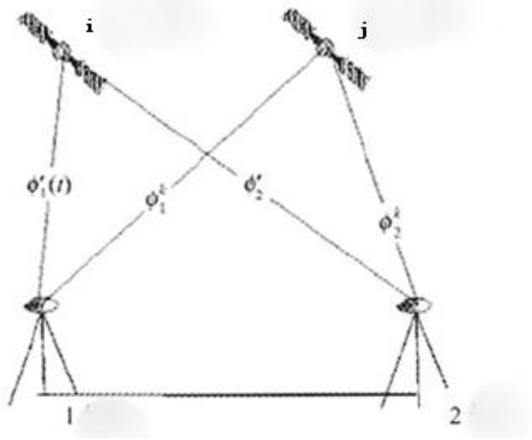

Figure 2: GPS deformation monitoring principle diagram based on single reference station

In the point 1 and 2, in the synchronous observation of satellites i , j , satellites i as reference station, simple difference between pseudo-range and carrier phase single difference equation of two satellite, You will get double difference positioning equation of pseudo-range and carrier phase:

$$
\begin{aligned}
\Delta\nabla\rho_{12}^{ij} &= \Delta\nabla R_{12}^{ij} + \Delta\nabla O_{12}^{ij} + \Delta\nabla Tr_{12}^{ij} \\
&+ \Delta\nabla I_{12}^{ij} + \Delta\nabla M_{12}^{ij} + \Delta\nabla \varepsilon_{12}^{ij} + \Delta\nabla e_{12}^{ij}
\end{aligned} \quad (3)
$$

$$
\begin{aligned}
\lambda\Delta\nabla\phi_{12}^{ij} &= \Delta\nabla R_{12}^{ij} + \Delta\nabla O_{12}^{ij} + \lambda\Delta\nabla N_{12}^{ij} \\
&+ \Delta\nabla Tr_{12}^{ij} + \Delta\nabla I_{12}^{ij} + \Delta\nabla M_{12}^{ij} + \Delta\nabla \varepsilon_{12}^{ij} + \Delta\nabla e_{12}^{ij}
\end{aligned} \quad (4)
$$

Double difference observation equations of carrier L1 and L2, we can get equation by subtract of this two equations:

$$\Delta\nabla\rho 1_{12}^{ij} - \lambda_1 \Delta\nabla\phi 1_{12}^{ij} = \lambda_1 \Delta\nabla N 1_{12}^{ij} \quad (5)$$

$$\Delta\nabla\rho 2_{12}^{ij} - \lambda_2 \Delta\nabla\phi 2_{12}^{ij} = \lambda_2 \Delta\nabla N 2_{12}^{ij} \quad （6）$$

The subtraction between two equations will cut or weaken kinds of errors, after ignore the effect of error in surplus, further transformed:

$$\Delta\nabla N 1_{12}^{ij} = \frac{\Delta\nabla\rho 1_{12}^{ij}}{\lambda_1} - \Delta\nabla\phi 1_{12}^{ij} \quad （7）$$

$$\Delta\nabla N2_{12}^{ij} = \frac{\Delta\nabla\rho 2_{12}^{ij}}{\lambda_2} - \Delta\nabla\phi 2_{12}^{ij} \tag{8}$$

In view of the above steps, the correlation between two carrier double difference ambiguity has not been considered, derivation as follows:

$$\lambda_1\Delta\nabla\phi 1_{12}^{ij} = \Delta\nabla R_{12}^{ij} + \lambda_1\Delta\nabla N_{12}^{ij} + \Delta\nabla Tr_{12}^{ij} + \frac{\Delta\nabla I_{12}^{ij}}{f_1^2} + \Delta\nabla M_{12}^{ij} + \Delta\nabla\varepsilon 1_{12}^{ij} + \Delta\nabla e1_{12}^{ij} \tag{9}$$

$$\lambda_2\Delta\nabla\phi 2_{12}^{ij} = \Delta\nabla R_{12}^{ij} + \lambda_2\Delta\nabla N_{12}^{ij} + \Delta\nabla Tr_{12}^{ij} + \frac{\Delta\nabla I_{12}^{ij}}{f_2^2} + \Delta\nabla M_{12}^{ij} + \Delta\nabla\varepsilon 2_{12}^{ij} + \Delta\nabla e2_{12}^{ij}$$

Subtract and make constant items

$$\begin{cases} l1 = \lambda_1 \cdot \Delta\nabla\phi 1_{12}^{ij} - \Delta\nabla R_{12}^{ij} - \Delta\nabla Tr_{12}^{ij} \\ l2 = \lambda_2 \cdot \Delta\nabla\phi 2_{12}^{ij} - \Delta\nabla R_{12}^{ij} - \Delta\nabla Tr_{12}^{ij} \end{cases} \tag{10}$$

Ignore double difference observation noise corresponding to L1 and L2, we can get formula from the formula (9) and (10):

$$f_1^2 \cdot (l1 - \lambda_1 \cdot \Delta\nabla N1_{12}^{ij}) = f_2^2 \cdot (l2 - \lambda_2 \cdot \Delta\nabla N2_{12}^{ij}) \tag{11}$$

Type (11) arrange to linear equation form:

$$\Delta\nabla N2_{12}^{ij} = \frac{\lambda_2}{\lambda_1} \cdot \Delta\nabla N1_{12}^{ij} + \frac{l2}{\lambda_2} - \frac{\lambda_2 \cdot l1}{\lambda_1^2} \tag{12}$$

Written as follows:

$$\Delta\nabla N2_{12}^{ij} = k \cdot \Delta\nabla N1_{12}^{ij} + b \quad \tilde{N}_1, \tilde{N}_2 \in Z \tag{13}$$

Where

$$k = \frac{\lambda_2}{\lambda_1} = \frac{77}{60} = 1.28\dot{3}$$
$$b = \frac{l2}{\lambda_2} - \frac{\lambda_2 \cdot l1}{\lambda_1^2} \tag{14}$$

Combined (7), (8) and (13), get equations

$$\begin{cases} \Delta\nabla N1_{12}^{ij} = \frac{\Delta\nabla\rho 1_{12}^{ij}}{\lambda_1} - \Delta\nabla\phi 1_{12}^{ij} & ① \\ \Delta\nabla N2_{12}^{ij} = \frac{\Delta\nabla\rho 2_{12}^{ij}}{\lambda_2} - \Delta\nabla\phi 2_{12}^{ij} & ② \\ \Delta\nabla N2_{12}^{ij} = k \cdot \Delta\nabla N1_{12}^{ij} + b & ③ \end{cases} \tag{15}$$

2.3. Condition adjustment

Generally, deformation monitoring is a long-term process, thus in the measurement of process, parameters can be determined, then we can determine the troposphere delay according to model, such as Saastamoinen model:

$$\Delta^{Trop} = \frac{0.002277}{\cos z}\left[p + \left(\frac{1255}{T} + 0.05 \right) e - \tan^2 z \right] (m)$$

where z = zenith angle
p = atmospheric pressure
T = temperature
e = local water vapor pressure

There are a lot of troposphere delay formulas, and will not be introduced here due to limited space. Due to the precise coordinates of benchmark and monitoring stations has been known, then k , b can be used as the known value. By use of ①②equations, we can obtain $\Delta\nabla N1{,}0_{12}^{ij}$, $\Delta\nabla N2{,}0_{12}^{ij}$ -initial value of $\Delta\nabla N1_{12}^{ij}$, $\Delta\nabla N2_{12}^{ij}$ Then use type (3) for condition adjustment.

Respectively, set v_1 , v_2 as the correct number of $\Delta\nabla N1_{12}^{ij}$ and $\Delta\nabla N2_{12}^{ij}$,③ can change into the following equation:

$$\Delta\nabla N2,0_{12}^{ij} + v_2 = k \cdot \left(\Delta\nabla N1,0_{12}^{ij} + v_1\right) + b$$

That is

$$\begin{bmatrix} k & -1 \end{bmatrix}\begin{bmatrix} v_1 & v_2 \end{bmatrix}^T + w = 0 \qquad (16)$$

Where:

$$w = k\Delta\nabla N1,0_{12}^{ij} - \Delta\nabla N2,0_{12}^{ij} + b$$

Condition adjustment:

$$AV + W = 0$$

Where:

$$A = \begin{bmatrix} k & -1 \end{bmatrix}$$
$$V = \begin{bmatrix} v_1 & v_2 \end{bmatrix}^{-1}$$

After calculated

$$\begin{bmatrix} v_1 & v_2 \end{bmatrix}^T = \begin{bmatrix} k & -1 \end{bmatrix}^T \bullet \frac{w}{k^2+1} \qquad (17)$$

Using the results to correct initial value $\Delta\nabla N1,0_{12}^{ij}$, $\Delta\nabla N2,0_{12}^{ij}$, after rounding we can determine integer ambiguity.

When we get the correct integer ambiguity, (2) can be changed into form of error equation

$$v_{x,i} = d_x + \lambda l_{P_1}^i N_{P_1,P_3}^1 - [\bullet] \qquad (18)$$

Where $[\bullet]$ is part of [] in (2). Due to limited space, the follow steps will not be showed in this paper.

3. EXPERIMENT

3.1. Description of experiment

Experiment had two groups of data in four sites (all is IGS station), the purpose was asked to compare the influence of the baseline length to the model, all data were downloaded from observation data IGS station, to verify calculating the feasibility of ambiguity resolution by the method. In the experiment, the observation data of August 10, 2010 were used, and sampling took its 50 epoch as experimental epoch, Used the accurate coordinates put online as observation results in first monitor observed, the dynamic simulation of the deformation monitoring, in this improved extraction method of deformation monitor information using single epoch, this paper only changed ambiguity resolution, therefore only verify the correctness of the ambiguity resolution. The data of two groups are shown below:

	Name	Known coordinates			Probably baseline length
		X	Y	Z	
First group	BOGO	3633738.861	1397434.215	5035353.494	107m
	BOGI	3633815.700	1397453.900	5035280.800	
Second group	KIRU	2251420.700	862817.278	5885476.773	4400m
	KIR0	2248123.105	865686.749	5886425.861	

Table 1: experimental site information sheet

The algorithm was checked by programming, computed the integer ambiguity of each epoch, and then compared with the known value. The comparison results as shown in table 2, due to limited space, only show part of the results:

Epoch	Satellite：31-11	
	L1(known as -20)	L2（known as -11）
	The algorithm	The algorithm
1	-20.10	-11.15
2	-20.11	-11.11
3	-20.15	-11.10
4	-20.11	-11.13
5	-20.10	-11.12
6	-20.10	-11.09
7	-20.12	-11.20
8	-20.14	-11.15
…	…	…
47	-20.16	-11.09
48	-20.11	-11.17
49	-20.14	-11.08
50	-20.09	-11.13

Table 2: the experimental results TAB of the first group

In the second experiment, ambiguity resolution according to this model and before rounding was failed.

3.2. Conclusion of experiment

We can seen from the data in the table 2, the integer ambiguity of theses 50 epochs, the maximum and minimum value was within 0.5 weeks, therefore, direct rounding can get correct result, did not need to undertake search work of integer ambiguity, improved the efficiency of the deformation monitoring. However, when range increased to 4000 m, the method showed its shortage, the ambiguity between maximum and minimum values had large difference, the solution was failure. Explained that the method was suitable in situation that baseline in short length , meet general characteristics of deformation monitoring, but for landslide monitoring and distance between benchmarks and monitoring stations in the much bigger, was not suitable, and the method needed to be improved.

In addition, due to the single epoch element method, the model avoid the repair of cycle slip, this method based on the existing methods , introduced the condition that two carrier ambiguity is related, and make full use of the observation data and correct the initial value by using Condition adjustment. For long distance benchmark station, through a single epoch to determine integer ambiguity and extract the deformation information is remained to continue to study, and the reason of this is that: In this model, through the subtraction between synchronous observation value, we can reach the purpose that eliminate the observation error of correlation, but the effective distance is limited, with the increased of space, the error of the correlation between two station become significantly weakened and difficult to determine the integer ambiguity, this is the reason why the second group of this experiment data decoded failure.

References

Gao Xingwei, 2002, The algorithmic research of GPS/GLONASS network RTK and it’s program realization, Wuhan University, China, pp. 45-63.

Wang Xinzhou, 2007, A new method for integer ambiguity resolution in GPS deformation monitoring, Geomatics and information science of wuhan university, 32(1), China.

Yu Xuexiang, 2002, The research of single epoch algorithm for the GPS deformation monitor information, Acta geodaetica ET cartographica sinica, 32(2), China.

Han Shaowei, 1999, Single-epoch algorithm resolution for real-time GPS attitude deformation with the aid of one-dimensional, Optical fiber Gyro[J].GPS solution, 3(1), China. pp. 5-12.

Li Zhenghang, 2005, GPS surveying and data processing, Wuhan University Press, Wuhan. pp. 78-119.

Li Shao, 2010, Research on algorithm and its realization for quick extraction of deformation information based on single epoch, Engineering of Surveying and Mapping, 19(2), China.

Acknowledgements

This work is funded by 2007CB310805, which belongs to 973 project, and I should finally like to express my gratitude to the supporter.

I would like to express my gratitude to all those who helped me during the writing of this thesis. I gratefully acknowledge the help of my supervisor, Ms. LiuHui, who has offered me valuable suggestions in the academic studies. In the preparation of the thesis， she has spent much time reading through each draft and provided me with inspiring advice. Without her patient instruction, insightful criticism and expert guidance, the completion of this thesis would not have been possible.

I also owe a special debt of gratitude to all the professors in GNSS Research Center, from whose devoted teaching and enlightening lectures I have benefited a lot and academically prepared for the thesis.