An Improved Extraction Method of Deformation Monitor Information Using Single Epoch

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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 benchmark time (first period observation), bench mark \( \mathbf{p}_1 \) is still, monitoring stations \( \mathbf{p}_2 \) occurs deformation. After deformation, the position of \( \mathbf{p}_2 \) become as \( \mathbf{p}_3 \), deformation show as \( \mathbf{d} \). Now employs deformation observation of monitoring time to get deformation \( \mathbf{d} \). In the form of a vector, \( \mathbf{d} \) can be expressed as:

\[
\mathbf{d} = \overrightarrow{\mathbf{p}_3} - \overrightarrow{\mathbf{p}_1} - \mathbf{b}
\]  

(1)

![Figure 1: Principle diagram](image)

To acquire deformation of the monitoring station \( \mathbf{p}_2 \) in...
the space, compute projection of this type to x, y, z -three coordinate transformation. Attend to the carrier phase observation single-difference model and orientation cosine, take point \( \mathbf{p}_2 \) in the direction of the x axis deformation, for example, we have

\[
d_2 = l_h^i \overline{p}_h^i - l_h^j \overline{p}_h^j - x_{h,2},
\]

\[
= -\lambda_h^i N_h^i - \lambda_h^j N_h^j.
\]

This type is similar as single-difference model, and the corresponding data processing model 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 \( l^i_{h,1} \) (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 \( N^i_{h,1} \). 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](image)

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:

\[
\Delta \overline{\rho}_{12}^i = \Delta \overline{R}_{12}^i + \Delta \overline{O}_{12}^i + \Delta \overline{Tr}_{12}^i
\]

\[
+ \Delta \overline{I}_{12}^i + \Delta \overline{M}_{12}^i + \Delta \overline{e}_{12}^i + \Delta \overline{e}_{12}^j
\]

\[
\lambda \Delta \overline{\phi}^i_{12} = \Delta \overline{R}_{12}^i + \Delta \overline{O}_{12}^i + \lambda \Delta \overline{N}_{12}^i
\]

\[
+ \Delta \overline{Tr}_{12}^i + \Delta \overline{I}_{12}^i + \Delta \overline{M}_{12}^i + \Delta \overline{e}_{12}^i + \Delta \overline{e}_{12}^j
\]

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

\[
\Delta \overline{\rho}_{12}^i - \lambda_1 \Delta \overline{\phi}_{12}^i = \lambda_1 \Delta \overline{N}_{12}^i
\]

\[
\Delta \overline{\rho}_{22}^i - \lambda_2 \Delta \overline{\phi}_{22}^i = \lambda_2 \Delta \overline{N}_{22}^i
\]

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

\[
\Delta \overline{N}_{12}^i = \frac{\Delta \overline{\rho}_{12}^i}{\lambda_1} - \Delta \overline{\phi}_{12}^i
\]
\[ \Delta V N 2_{12}^{ij} = \frac{\Delta V \rho 2_{12}^{ij}}{\lambda_2} - \Delta V \phi 2_{12}^{ij} \quad (8) \]

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

\[
\begin{align*}
\lambda_1 \Delta V \phi 1_{12}^{ij} &= \Delta V R_1^{ij} + \lambda_1 \Delta V N_1^{ij} + \Delta V T_1^{ij} \\
&+ \frac{\Delta V I_{12}^{ij}}{f_1^2} + \Delta V M_1^{ij} + \Delta V e 1_{12}^{ij} + \Delta V e 1_{12}^{ij} \\
\lambda_2 \Delta V \phi 2_{12}^{ij} &= \Delta V R_2^{ij} + \lambda_2 \Delta V N_2^{ij} + \Delta V T_2^{ij} \\
&+ \frac{\Delta V I_{12}^{ij}}{f_2^2} + \Delta V M_2^{ij} + \Delta V e 2_{12}^{ij} + \Delta V e 2_{12}^{ij}
\end{align*}
\]

\[ (9) \]

Subtract and make constant items

\[
\begin{cases}
L1 = \lambda_1 \cdot \Delta V \phi 1_{12}^{ij} - \Delta V R_1^{ij} - \Delta V T_1^{ij} \\
L2 = \lambda_2 \cdot \Delta V \phi 2_{12}^{ij} - \Delta V R_2^{ij} - \Delta V T_2^{ij}
\end{cases}
\]

\[ (10) \]

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

\[ f_1^2 \cdot (L1 - \lambda_1 \cdot \Delta V N 1_{12}^{ij}) = f_2^2 \cdot (L2 - \lambda_2 \cdot \Delta V N 2_{12}^{ij}) \]

\[ (11) \]

Type (11) arrange to linear equation form:

\[ \Delta V N 2_{12}^{ij} = \frac{\lambda_2}{\lambda_1} \cdot \Delta V N 1_{12}^{ij} + \frac{L2}{\lambda_2} - \frac{\lambda_2 \cdot L1}{\lambda_1^2} \]

\[ (12) \]

Written as follows:

\[ \Delta V N 2_{12}^{ij} = k \cdot \Delta V N 1_{12}^{ij} + b \quad \tilde{N}_1, \tilde{N}_2 \in Z \]

\[ (13) \]

Where

\[ k = \frac{\lambda_2}{\lambda_1} = \frac{77}{60} = 1.28 \]

\[ b = \frac{L2}{\lambda_2} - \frac{\lambda_2 \cdot L1}{\lambda_1^2} \]

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

\[
\begin{cases}
\Delta V N 1_{12}^{ij} = \frac{\Delta V \rho 1_{12}^{ij}}{\lambda_1} - \Delta V \phi 1_{12}^{ij} \quad (1) \\
\Delta V N 2_{12}^{ij} = \frac{\Delta V \rho 2_{12}^{ij}}{\lambda_2} - \Delta V \phi 2_{12}^{ij} \quad (2) \\
\Delta V N 2_{12}^{ij} = k \cdot \Delta V N 1_{12}^{ij} + b \quad (3)
\end{cases}
\]

\[ (15) \]

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 \((1),(2)\) equations, we can obtain \( \Delta V N 1_{12}^{ij}, \Delta V N 2_{12}^{ij} \) -initial value of \( \Delta V N 1_{12}^{ij}, \Delta V N 2_{12}^{ij} \). Then use type (3) for condition adjustment.
Respectively, set $v_1, v_2$ as the correct number of\n$\Delta \nabla N_{1i}^{ij}$ and $\Delta \nabla N_{2i}^{ij}$, can change into the following\nequation:\n\[ \Delta \nabla N_{2i} + v_2 = k \left( \Delta \nabla N_{1i} + v_1 \right) + b \]\n\[ (\Delta \nabla N_{2i} + v_2) + w = 0 \] \hspace{1cm} (16)\nThat is\n\[ w = k \Delta \nabla N_{1i} - \Delta \nabla N_{2i} + b \]\nCondition adjustment:\n\[ AV + W = 0 \]
Where:\n\[ A = \begin{bmatrix} k & -1 \end{bmatrix}, \quad V = \begin{bmatrix} v_1 \ v_2 \end{bmatrix}^{-1} \]
After calculated\n\[ \begin{bmatrix} v_1 \\ v_2 \end{bmatrix}^T = \begin{bmatrix} k & -1 \end{bmatrix} \begin{bmatrix} \frac{w}{k^2 + 1} \end{bmatrix} \] \hspace{1cm} (17)\nUsing the results to correct initial\nvalue $\Delta \nabla N_{1i}^{ij}$, $\Delta \nabla N_{2i}^{ij}$, after rounding we can determine integer ambiguity.

When we get the correct integer ambiguity, (2) can be changed into form of error equation\n\[ v_{a_d} = d + \lambda \cdot \begin{bmatrix} N_{1i}^{ij} \\ N_{2i}^{ij} \end{bmatrix} \] \hspace{1cm} (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:

<table>
<thead>
<tr>
<th>Name</th>
<th>Known coordinates</th>
<th>Probab. baseline length</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$X$</td>
<td>$Y$</td>
</tr>
<tr>
<td>First group</td>
<td>363373</td>
<td>363381</td>
</tr>
<tr>
<td>BOGO</td>
<td>8.861</td>
<td>1397434</td>
</tr>
<tr>
<td>BOGI</td>
<td>363381</td>
<td>5.700</td>
</tr>
<tr>
<td>Second group</td>
<td>225142</td>
<td>224812</td>
</tr>
<tr>
<td>KIRU</td>
<td>225142</td>
<td>224812</td>
</tr>
<tr>
<td>KIR0</td>
<td>224812</td>
<td>225142</td>
</tr>
</tbody>
</table>

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  

<table>
<thead>
<tr>
<th>Satellite: 31-11</th>
<th>Satellite: 31-11</th>
</tr>
</thead>
<tbody>
<tr>
<td>L1 (known as -20)</td>
<td>L2 (known as -11)</td>
</tr>
<tr>
<td>The algorithm</td>
<td>The algorithm</td>
</tr>
<tr>
<td>1</td>
<td>-20.10</td>
</tr>
<tr>
<td>2</td>
<td>-20.11</td>
</tr>
<tr>
<td>3</td>
<td>-20.15</td>
</tr>
<tr>
<td>4</td>
<td>-20.11</td>
</tr>
<tr>
<td>5</td>
<td>-20.10</td>
</tr>
<tr>
<td>6</td>
<td>-20.10</td>
</tr>
<tr>
<td>7</td>
<td>-20.12</td>
</tr>
<tr>
<td>8</td>
<td>-20.14</td>
</tr>
<tr>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>47</td>
<td>-20.16</td>
</tr>
<tr>
<td>48</td>
<td>-20.11</td>
</tr>
<tr>
<td>49</td>
<td>-20.14</td>
</tr>
<tr>
<td>50</td>
<td>-20.09</td>
</tr>
</tbody>
</table>

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.

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