Application and Research on the 3-D adjustment of control network in particle accelerator

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Outline

1. The traditional 3-D network adjustment
2. The modified 3-D network adjustment and
3. The program
4. The result
5. The question

1. The traditional 3-D network adjustment

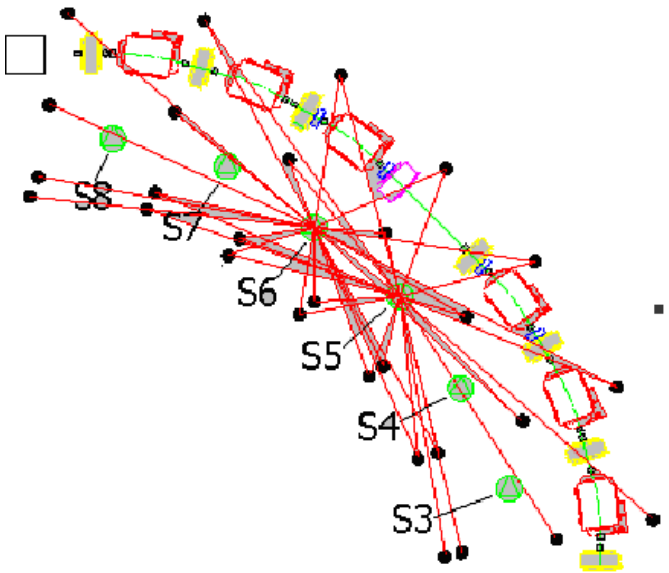
- It's the traditional 3-D network adjustment model which is including with the relationship between the horizontal angle, the vertical angle, the distance and the coordinate X, Y, Z.

$$\begin{bmatrix} H_{Z_{ik}} \\ V_{Z_{ik}} \\ S_{ik} \end{bmatrix} = \begin{bmatrix} arctg \dfrac{Y_{ik}}{X_{ik}} \\ arc\cot \dfrac{Z_{ik}}{\sqrt{X^2_{ik} + Y^2_{ik}}} \\ \sqrt{X^2_{ik} + Y^2_{ik} + Z^2_{ik}} \end{bmatrix}$$

- Question:
- 1) It's difficult to linearize the relationship
- 2) It's necessary to have the initial value for the calculation's convergence.

2. The modified 3-D network adjustment (1/4)

- The laser tracker measures the points in the accelerator tunnel like this. Each of the two stations have some common measured points, and get the observations (X,Y,Z) translated by traditional observations(Hz, V, S).



- Questions:
- 1) the modified observations
- 2) the modified 3-D adjustment model
- 3) the fixed weight and Test

2. The modified 3-D network adjustment (2/4)

- 1) the modified observations
- The modified observations (also called Generation observation) is translated from the traditional observations like this.

$$\begin{cases} X_{ik} = S_{ik} \cdot \sin V_{Z_{ik}} \cdot \cos H_{Z_{ik}} \\ Y_{ik} = S_{ik} \cdot \sin V_{Z_{ik}} \cdot \sin H_{Z_{ik}} \\ Z_{ik} = S_{ik} \cdot \cos V_{Z_k} \end{cases}$$

- 2) the modified 3-D adjustment model
- First, the translated relationship is between the theory value and the measured observations like this. It just have the coordinates (X,Y,Z) and the rotation matrix (R).

$$\begin{bmatrix} X_{ik} \\ Y_{ik} \\ Z_{ik} \end{bmatrix} = R \bullet \begin{bmatrix} X_k - X_i \\ Y_k - Y_i \\ Z_k - Z_i \end{bmatrix}$$

- Second, the relationship could be changed to this because of the known value X_{ik}、Y_{ik}、Z_{ik} . We can get the modified model 1st if the each element is uncorrelated.

$$R^{-1} \begin{bmatrix} X_{ik} \\ Y_{ik} \\ Z_{ik} \end{bmatrix} - \begin{bmatrix} X_k - X_i \\ Y_k - Y_i \\ Z_k - Z_i \end{bmatrix} = 0$$

2. The modified 3-D network adjustment (3/4)

- We also can get the modified model 2nd considering each element of R is related. Because the R is made up 3 rotated angles and each station should have leveling first, the R could be simplified with 2 little rotated angles like this. $\sin\varphi=\varphi$, $\cos\varphi=1$; $\sin w=w$, $\cos w=1$.

$$R=\begin{bmatrix}\cos\varphi\cdot\cos\kappa-\sin\varphi\cdot\sin w\cdot\sin\kappa & -\cos\varphi\cdot\sin\kappa-\sin\varphi\cdot\sin w\cdot\cos\kappa & -\sin\varphi\cdot\cos w\\ \cos w\cdot\sin\kappa & \cos w\cdot\cos\kappa & -\sin w\\ \sin\varphi\cdot\cos\kappa+\cos\varphi\cdot\sin w\cdot\sin\kappa & -\sin\varphi\cdot\sin\kappa+\cos\varphi\cdot\sin w\cdot\cos\kappa & \cos\varphi\cdot\cos w\end{bmatrix}$$

$$\Downarrow$$

$$R'=\begin{bmatrix}\cos\kappa-\varphi\cdot w\cdot\sin\kappa & -\sin\kappa-\varphi\cdot w\cdot\cos\kappa & -\varphi\cdot\cos w\\ \sin\kappa & \cos\kappa & -w\\ \varphi\cdot\cos\kappa+w\cdot\sin\kappa & -\varphi\cdot\sin\kappa+w\cdot\cos\kappa & 1\end{bmatrix}$$

2. The modified 3-D network adjustment (4/4)

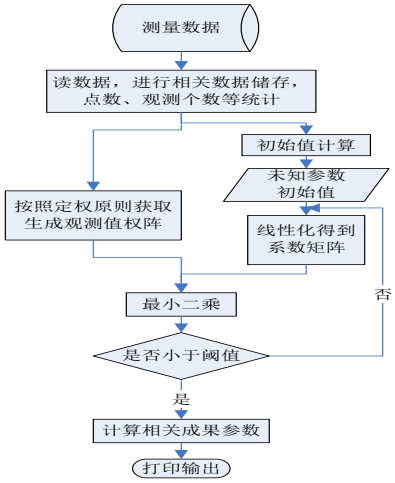
- 3) the fixed weight and test
- First, we should get the prior mean square error of the traditional observations (Hz,V,S). So it's easy to get the modified observations' mean square error according to modified relationship above and the propagration of error.

$$D_{XX_{ik}} = K \cdot\cdot D_{LL_{ik}} \cdot K^T$$

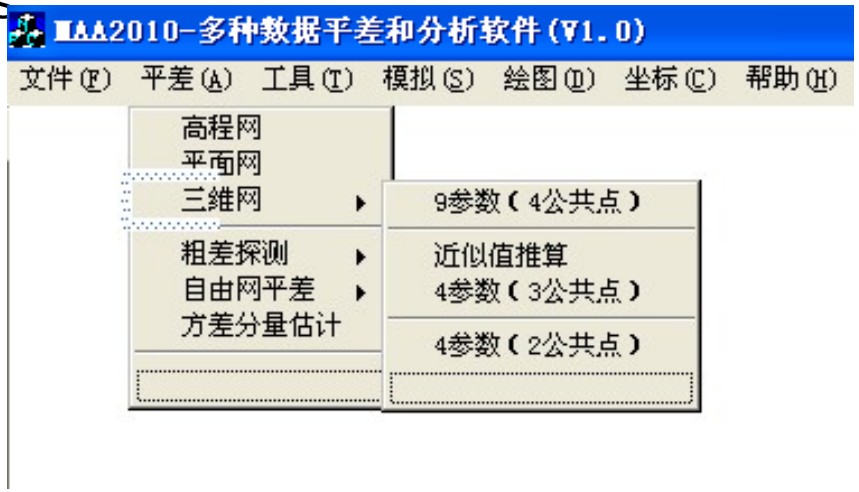
- Second, it's to test the fixed weight if the prior unit weight mean square error is equal to the posteriori.

3. The program

- The program is made by visual C++ and named “Multiple data Adjustment and Analysis” with its block diagram like this.



- The program has realized the modifed adjustment model 1st and model 2nd.
  It also includes some functions such as
  the gross error detection,
  the error ellipse,
  the leveling adjustment, and so on.



4. The result

- We have a experiments with 3-years accelerator tunnel measured data in BEPC. And we have done the difference between it and the result about "Survey" program computation. (Unit: mm)

Year	Precision		The min	The Max	The Ave	The MSA
2009	1.1″ (Hz)	X	-1.000	2.313	0.267	0.976
	2.0″ (V)	Y	-0.640	0.694	0.004	0.279
	0.18mm(S)	Z	-4.18	4.359	0.084	2.454
2010	1.0″ (Hz)	X	-1.490	1.912	0.050	0.938
	1.4″ (V)	Y	-1.190	0.747	-0.23	0.470
	0.2mm(S)	Z	-0.690	2.149	-0.319	0.791
2011	1.3″ (Hz)	X	-1.748	1.410	0.003	0.799
	1.3″ (V)	Y	-1.379	2.156	-0.071	0.839
	0.35mm(S)	Z	-2.189	2.615	-0.199	1.299

5. The question

- 1) How to get large data and compute faster?
- The longer the accelerator tunnel, the more the measured points. So we should compress the large data and have optimization algorithm.
- 2) How to get higher precision with the propagration of error?
- Each station are relative with the common measured points. The error from measurement is going from measuring common points to the laser tracker, and then to the next station's instruments and measured points. So it becomes biger with station numbers. Sometime, the error of laser tracker's position is more than the instrument stationed precision.
- So we should get higher precision of instrument's position by other way.

The end, thanks!

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