Using GPS Attitude Determination in Tower Inclination Monitoring of Overhead Transmission Lines

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ABSTRACT:

Based on the analysis of the feasibility of using GPS attitude determination in slope monitoring of telegraph pole, the scheme was proposed. The experiment was carried out in proving ground. The experimental result shows that the method can satisfy criterion of power industry as well can be used in slope monitoring of telegraph pole.

1. INTRODUCTION

In mine area, subside of land can induce inclination of over head transmission lines tower. Disasters resulting from the collapse of these towers do not occur without warning. Strategic monitoring in a hazardous area can create an awareness of any impending danger, resulting in quicker emergency response times and disaster prevention (Jason Bond, 2008).

Now days, artificially check up method is adopted by the department of electricity power for inclination monitoring. Thus, too many manpower and financial resources are columned. Alternatively, we can say this is an inefficiently method. Engineering projects that require deformation monitoring frequently utilize geodetic instruments to measure displacements of target points located in the deformation zone. In situations where control stations and targets are separated by a kilometre or more, GPS can offer higher precision position updates at more frequent intervals than can normally be achieved using total station technology.

This paper introduces GPS attitude determination to monitor the inclination of over head transmission tower. The method need not establish the control point; also it can satisfy criterion of power industry as well can be used in inclination monitoring of buildings.

2. GPS ATTITUDE DETERMINATION

Three noncollinear antennas attached to a rigid body provide attitude. The only constraint on the antenna placement required for attitude determination is that the three antennas not lie on the same line (Ronald A. Brown, 1992).

In GPS attitude determination, we need to distinguish two coordinate frames: the local level coordinate frame (LLF), and the antenna body frame (ABF). The former one is described in (Hofmann-Wellenhof. 2008) and can be obtained by converting the coordinates of the slave antennas given in the Earth Cantered Earth Fixed (ECEF) coordinate frame with respect to the coordinate of the master antenna. The latter one is formed by the GPS antennas. Here we assume that the antennas are mounted on a rigid platform, i.e., the relative distances between the antennas remain unchanged. Actually, three antennas are sufficient to determine the ABF. The origin is chosen as the position of the phase centre of antenna 1, namely the master antenna. The Y-axis is assumed along with the baseline from antenna 1 to antenna 2. The X-axis is perpendicular with the Y-axis and lies in the plane defined by antenna 1, 2 and 3. The Z-axis is perpendicular to both of the X and Y-axis and points upwards (Zhen Dai, 2009).

GPS determination is generally defined as matrix transformations. Euler angles are adopted in this study. The misalignment between the LLF and the ABF is actually formed by three sequential rotations corresponding to three Euler angels. Each rotation can be expressed using a rotation matrix. These three rotation matrices can also be generalized into a combined rotation matrix when multiplying them in the specific order (Zhen Dai, 2009). The following matrix transformations model reflects the relationship between the LLF and the ABF :

$$\begin{bmatrix} x^b \\ y^b \\ z^b \end{bmatrix} = R_2(\Phi)R_1(\theta)R_3(\Psi)\begin{bmatrix} x^l \\ y^l \\ z^l \end{bmatrix} \quad (1)$$

In Eq. 1, $[x^b \quad y^b \quad z^b]^T$ denote the ABF and $[x^l \quad y^l \quad z^l]^T$ denote the LLF. The WGS-84 coordinate of the baseline 1-2 and 1-3 can be obtained by processing the GPS phase carrier observation. Then the LLF can be obtained from Eq. 2:

$$\begin{bmatrix} x^b \\ y^b \\ z^b \end{bmatrix} = \begin{bmatrix} -\sin\alpha & \cos\alpha & 0 \\ -\sin\beta\cos\alpha & -\sin\beta\sin\alpha & \cos\beta \\ \cos\beta\cos\alpha & \cos\beta\sin\alpha & \sin\beta \end{bmatrix}\begin{bmatrix} x^e \\ y^e \\ z^e \end{bmatrix} \quad (2)$$

In Eq. 2, $[x^e \quad y^e \quad z^e]^T$ denote the baseline in WGS-84. α , β denote the longitude and the latitude of body.

If the LLF coordinates of antenna 2 and antenna 3 are $(x_2 \quad y_2 \quad z_2)$ and $(x_3 \quad y_3 \quad z_3)$ .we can compute the roll angle, pitch angle and yaw angle:

$$pitch = -\arctan(z_2 / \sqrt{x_2^2 + y_2^2}) \quad (3)$$

$$yaw = -\arctan(x_2 / y_2) \quad (4)$$

$$roll = -\arctan(z_3' / x_3') \quad (5)$$

Here, the fundamental equation relating the GPS carrier phase difference are resolved to determine the baseline in WGS-84.

3. USING GPS ATTITUDE DETERMINATION FOR OVERHEAD TRANSMISSION LINES INCLINATION MONITORING

3.1 Configuration of the Tower Inclination Monitoring Equipment

Now days, land subsidence becomes popular in city zone, mine area and etc because of excessive exploitation of groundwater or mineral resources. As a result, the overhead transmission lines tower will incline. If the inclination exceeds the limitation, the tower will collapse and be disastrous.

Generally, the collapse of overhead transmission lines tower does not happen abruptly. The inclination of the tower often is very slowly. That is to say, the tower inclination can be monitored by special method and the collapse can be forecast through the monitoring data.

In power transmission management department, some instruments such as optical fiber sensors are used to monitor inclination of the tower.

GPS is widely used in geodesy, precise project surveying. Comparing with other surveying instruments, GPS monitoring method has the advantage of high precision, automatically obtaining coordinate in 3-demension and all-weather working. In common, high precision GPS monitoring employed the double difference carrier phase. This method need to set up some steady datum marks which is far from deformation area and doesn't move during the monitoring period.

In this paper, we employ the GPS attitude determination method to monitor the inclination of overhead transmission lines tower. The method needn't the stable datum marks, three GPS receivers are fixed on the top of the tower. The only constraint is relative distances between the antennas remain unchanged. Also, the antenna placement required for attitude determination is that the three antennas not lie on the same line. The relationship of three antennas is depicted in the following figure (Figure. 1).

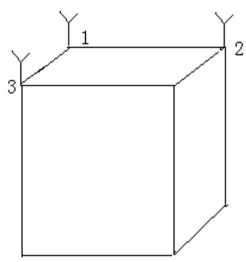

Figure 1. Relationship of three antennas

The fixed GPS antenna is showed in figure 2. The antennas are installed on the three corners of the tower operatively. They are fixed on the body of the tower tightly and will not sway with the wind. Thus, the antennas will displace with the tower. Of course they can reflect the deformation of the tower.

Figure 2. Photo of fixed antenna

Then equipment is developed based on the principle of GPS attitude determination. The configuration of the equipment is illustrated in figure 3.

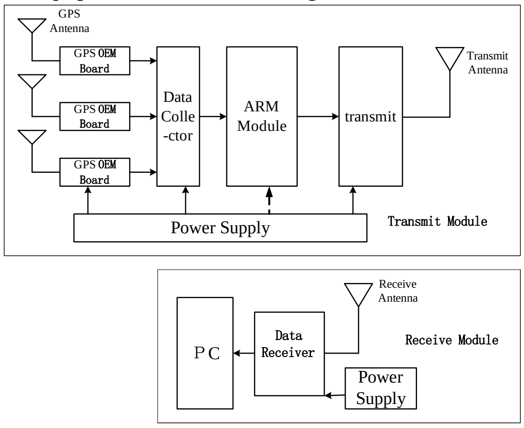

Figure 3 Configuration of the monitoring equipment

The GPS OEM board processes the signal of GPS antenna then sends the navigation data; phase and code observation to data collector. The data collector collects the monitoring data of three GPS OEM board and sends them to ARM module. The programs embedded in this ARM cover the RINEX data analysis, double differential positioning, coordinate conversion, attitude determination, and other auxiliary functions. After forming the baselines through double-differenced carrier phase code observables, the attitude parameters are obtained by applying the direct attitude computation. The auxiliary functions including cycle slips detection and repairing, reference satellite choosing, satellite position computation and etc.

The double-differential equation can be solved independently for each antenna separation vector, 1-2 and 1-3. The two vectors can then be used to compute the attitude associated with the plane containing the two vectors. Thus, the fair line inclination and the orientation inclination of the tower can be obtained.

3.2 Accuracy analysis

We can get equation (6), (7), (8) by differencing equation (3), (4), (5) separately(Ying Tan, 2007).

$$dp = \frac{(x_2^2 + y_2^2)dz_2 - z_2 x_2 dx_2 - z_2 y_2 dy_2}{\sqrt{x_2^2 + y_2^2}(x_2^2 + y_2^2 + z_2^2)} \qquad (6)$$

$$dy = \frac{y_2 dx_2 - x_2 dy_2}{x_2^2 + y_2^2} \quad (7)$$

$$dr = \frac{x_3' dz_3' - z_3' dx_3'}{x_3' + z_3'} \quad (8)$$

From error propagation principle, the errors of pitch (σ_p) yaw (σ_y) and roll (σ_r) can be obtained. If we ignore the correlations of baseline 1-2 and 1-3, the errors of three angles yields:

$$\sigma_p \leq \sigma_{\max} / L_{12} \quad (9)$$

$$\sigma_y \leq \sigma_{\max}(\sigma_{x_2}, \sigma_{y_2}) / L_{12} \cos\alpha \quad (10)$$

$$\sigma_r \leq \sigma_{\max}(\sigma_{x_3'}, \sigma_{z_3'}) / L_{13} \cos\alpha \quad (11)$$

The three dimensional accuracy from the double-differential positioning can achieve millimeter level. This implies that the accuracy of the attitude parameters will be high precision.

3.3 An experiment results

A static experiment is carried out to test the performance of the method. The GPS measurements are acquired by using three Crescent® GPS OEM board and three Leica GPS antennas. The antennas are fixed on the three corners on the body of the over head transmit lines tower.

The GPS antennas receive GPS signals simultaneity. The signals are then transferred to the GPS OEM board and the measurements are then converted to RINEX format. The observation session takes about 60 min with 1 Hz data rate. By solving the data of three GPS OEM board in ARM board, we can obtain the baselines 1-2 and 1-3 in WGS-84 coordinate system.

The errors of three angles are depicted in Figure 2. The standard error of pitch, yaw and roll is 0.0444 degree, 0.0455 degree and 0.0316 degree separately. The pitch and roll reflect the fair line inclination and orientation inclination. The precision can satisfy the criterion of power industry.

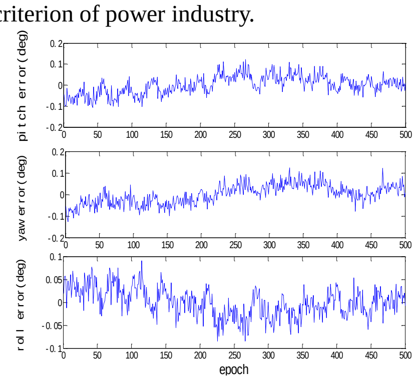

Figure 2. Error of three angles

4. CONCLUSION

Using GPS attitude determination to monitor inclination of over head transmission lines tower has a lot of advantages such as all weather conditional working, low cost, high precision and no need of steady datum marks. We adopt the GPS OEM board in order to save costs. This paper introduces the principal of the method. Simple experiment proves the precision can satisfy the criterion of power management department. The electromagnetism interface and other factors have not been considered. These things will be research in following work.

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