Research about the on-line system for monitoring the geological subsidence of transmission tower based on high-precision positioning of Beidou

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Abstract—This article proposes an innovative method to achieve Beidou high-precision positioning. Then, the online monitoring physical information system of transmission pole tower is constructed with Beidou high precision positioning and inclination measurement information as the data source. The perception layer is Beidou high-precision positioning sensor and inclination measurement sensor, the data transmission layer is the way of combining wireless private network with wired private network, and the application control layer is the data processing center, which presents the results of analyzing sensor data to the user in a visual interface. The system can send an early warning message to the user at the very early stage of the deformation of the transmission pole tower, So that the user can take measures in time.

1. INTRODUCTION
Overhead line is the main carrier of power transmission, and transmission tower is the structural foundation supporting overhead line. The factors affecting the structural stability of transmission tower include: geological disasters, hail, ice disaster and other meteorological factors, uneven operation, construction near the foundation and other human factors, bar tower design is unreasonable, component corrosion, bolt loosening and other pole tower itself, as well as external force damage and other unexpected circumstances, etc. During the life cycle of the transmission pole tower, the power pole tower will fluctuate and adjust its attitude under the action of external factors. When a certain limit is exceeded, there may be deformation, tilting or even dumping accidents, seriously affecting the stability and safety of power supply[1~3].

The monitoring of millimeter-level variables can be realized by using the ground base station to correct the positioning data of Beidou[4], and the attitude adjustment of the transmission pole tower can be accurately monitored by the use of Beidou positioning technology. Literature[5] puts forward a concept of using Beidou system positioning to realize on-line monitoring of transmission ower, but the basic positioning service used by Beidou can only reach 10m positioning accuracy. The monitoring of the millimeter-shaped variable of the tower is realized by using a single reference station, which requires the installation of a base station near the tower, which improves the cost of the system application while limiting the application conditions[6]. There has also been a lot of research on the installation of inclination sensors on transmission pole towers to monitor the attitude adjustment of pole towers[7~9]. The slide and settling of the tower can be obtained by locating the data in Beidou and the tilt and offset
of the tower can be obtained by the inclination measurement data. The comprehensive positioning and inclination measurement information of Beidou can make a more comprehensive and comprehensive assessment of the attitude adjustment of the tower\[^4, 7–9\].

In this paper, a method for high-precision positioning is proposed by using Beidou satellite navigation data, then the design and implementation method of the information physics system of the transmission tower online monitoring is explained, and the effectiveness of monitoring is analyzed by the application example of the system.

2. HIGH PRECISION POSITIONING TECHNOLOGY OF BEIDOU

Beidou Satellite Navigation System obtains the location information of the anchor point by calculating the signal transmission time between the anchor point and the navigation satellite to find the distance between the anchor point and the navigation satellite. However, the sub-meter positioning service provided by Beidou positioning system is difficult to meet the needs of monitoring the change of the attitude of the pole tower. This paper corrects the error of satellite positioning by adding a base station on the ground\[^10\].

The \(s\) is the point of tower to be located, its spatial coordinates are assumed to be \((x, y, z)\). The \(i\) is the number of navigation satellites (\(i=1, 2, 3, 4\)). The locations of navigation satellites are assumed that their spatial coordinates are \((x_1, y_1, z_1)\). The following relationships exist:

\[
\begin{align*}
(x-x_1)^2 + (y-y_1)^2 + (z-z_1)^2 &= (t_i - t_s - t_0)^2 \\
(x-x_2)^2 + (y-y_2)^2 + (z-z_2)^2 &= (t_i - t_s - t_0)^2 \\
(x-x_3)^2 + (y-y_3)^2 + (z-z_3)^2 &= (t_i - t_s - t_0)^2 \\
(x-x_4)^2 + (y-y_4)^2 + (z-z_4)^2 &= (t_i - t_s - t_0)^2
\end{align*}
\]

where, \(t_{ei}\) is the time of electromagnetic wave propagation between the locations of navigation satellite \(i\) and the positioning point of tower to be measured \(s\); \(t_i\) is the time difference between the navigation satellite and the headquarters clock; \(t_s\) is the time difference between the positioning point to be measured and the clock of the headquarters; \(v_c\) is the speed of light. \(t_{ei}\) is computed from the relationship between \(i\) and \(s\). \((x_1, y_1, z_1), t_{ei}, t_i, v_c\) are known quantities. \((x, y, z)\) and \(t_{ei}\) are unknown. The equations can be used to find the spatial coordinates \((x, y, z)\) of \(s\).

Because of the influence of ionosphere, troposphere on electromagnetic wave reflection and electromagnetic wave transmission channel, there are errors in \(t_{ei}\).

The data in the ground base station data equation (1) is pushed back. For the ground base station, \(t_s\) are known. Time of electromagnetic wave propagation between navigation satellite \(i\) and base station \(t_{ei}\) is unknown. Four known quantities in the original equation group are converted to unknown quantities and four unknown quantities are converted to known quantities. The joint cube system finds the time of electromagnetic wave propagation \(t_{ei}^{\delta}\) between the navigation satellite \(i\) and the base station. The time of transmission of electromagnetic waves between the navigation satellite and the base station is obtained by communication between the base station and the navigation satellite.

The error formula is as follows

\[
\Delta t_{ei} = t_{ei}^{\delta} - t_{ei}
\]

The error \(t_{ei}\) of each anchor point is provided by four navigation satellites. Each anchor point is corrected by three nearby base stations using the same positioning satellite data.

Based on the geographic location information obtained by the location point to communicate directly with the navigation satellite, the system background matches the nearest three base stations using the same navigation satellite based on geographical location (Figure 1).
According to the location information, the distance between the location point and the three base stations is $d_1$, $d_2$, $d_3$. (3) is the formula of the error correction value $\Delta t_{ci}^0$ which is the point to be located:

$$\Delta t_{ci}^0 = \frac{d_2 d_3 \Delta t_{ci}^1 + d_1 d_3 \Delta t_{ci}^2 + d_1 d_2 \Delta t_{ci}^3}{d_1^2 d_2^2 + d_2^2 d_3^2 + d_1^2 d_3^2}$$  \hspace{1cm} (3)

The time error of electromagnetic wave propagation with navigation satellite obtained by 3 base stations are $\Delta t_{ci}^1$, $\Delta t_{ci}^2$, $\Delta t_{ci}^3$.

Furthermore, the corrected positioning point and the propagation time of electromagnetic wave of the navigation satellite can be shown in (4):

$$t_{ci} = t_0 + \Delta t_{ci}$$  \hspace{1cm} (4)

By solving the position of the point to be measured again, the Beidou high precision positioning information of the point to be measured can be obtained. The displacement data of the point to be located can be obtained by comparing the difference of the positioning information before and after the point to be located.

Figure 2 location distribution of base stations

The Beidou Auxiliary Positioning Base Station System relied on in this paper was officially put into operation on May 18, 2016. So far, there are more than 2700 working base stations in China. Up to now, cm-level positioning service can cover 20 provinces and cities in China. Specific to the areas of China Southern Power Grid, has achieved the millimeter service coverage.

Most of the transmission towers are located in remote areas with inconvenient transportation. It consumes a lot of labor costs while affecting the real-time monitoring. It is particularly necessary to build an information physical system covering on-line monitoring of transmission towers.[11]

The sensing layer consists of sensors installed on the transmission tower. The specific applications include the transmission tilt sensor of Beidou short message and the high-precision positioning sensor of Beidou.

The data transmission layer is a combination of wireless private network and wired private network. The transmission tower is connected to GPRS network by wireless communication module and the wireless network is connected by VPN agent. In the application, the mobile 4G private network is adopted to upload the navigation satellite communication data once in 10 seconds, and the required bandwidth is 5Mbps. The base station is accessed by wired private network, using carrier private line, and the required bandwidth is 10Mbps.
The application control layer is the data processing center. The functions of the data processing center include: obtaining Beidou high-precision positioning information according to Beidou sensor location information and base station information, comprehensive analysis of the information provided by the sensor, providing early warning information to users according to changing trends, change amount, mutation amount, etc., and presenting transmission tower history/real-time monitoring information and alarm information to the user in a visual interface on the client side.

![System structure diagram](image)

**Figure 3** system structure diagram

3. **SYSTEM APPLICATION EXAMPLES**

A 110kV line tower in Guangdong is located on the hillside of hilly area. In late April 2019, because of the planning of the municipal department, there is road construction at 50m northeast of the tower, which requires tunnel excavation and blasting.

![Geographical location of tower](image)

**Figure 4** geographical location of tower

The transmission tower is located in the hilly area and the precipitation is large. The construction operation may cause the tower to slip and tilt. The transmission line operation and maintenance unit takes the tower as the key control object and provides it with an online monitoring system. Each tower body and slope has a Beidou high-precision positioning sensor for monitoring the displacement and settlement trend of the tower body and slope. A tilt sensor for the transmission of two-axis Beidou short messages is installed in the pole tower to monitor the attitude change of the pole tower.

![Tilt sensor data transmitted by Beidou short message(mm)](image)

**Figure 5** Tilt sensor data transmitted by Beidou short message(mm)

The variation of positioning data of transmission tower body and slope is less than 5mm, and the tower body and infrastructure are stable. According to the data obtained by the tilt sensor, the tower
body is relatively stable along the line, the inclination angle of the tower body changes periodically perpendicular to the line, the inclination rate is less than 0.006, and the change of tower attitude is within the allowable range. The data obtained by the system is basically consistent with the data measured by line operation and maintenance.

4. CONCLUSIONS
This paper provides a construction idea of transmission tower on-line monitoring information physical system integrating Beidou high-precision positioning. The on-line monitoring function provides a guarantee for the operation of transmission equipment in controllable and controlled state.

Next step, we will use the established information physics system platform as the basis, according to the actual needs of the rod tower to add micrometeorine, video monitoring, wire arc prolapse measurement, wire pull measurement and other sensor modules, further improve the system perception function, to improve the operation of transmission system and the lean level of maintenance.

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