Monitoring the Deformation of Cableways

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1 Introduction

Normally cableways are rectilinear between their two ends. In this case the rolls, which guide the cable over the towers, support the axial (normal) force. As a matter of fact, if not all the towers stay exactly in a straight line, the strain of the cable and the stress and the abrasion on the rolls rise, increasing the consequent risk of derailment. The deviations of the position of the towers from the planned layout are due to local sliding or sinking of the foundation or other mechanical movements. As these events are unpredictable, continuous monitoring is required.

Seeing above facts the concerning Swiss controlling agency has published an ordinance regulating the construction and the operation of cableways. The ordinance provides the carrier of cableways to undertake periodically surveying. The requested analyses are based on geodetic observation. Because of the limitation of viewing, and due to the typical mountainous topography which surrounds the most cableways, surveying them with conventional methods can be a difficult task. Furthermore applying conventional methods to a similar assignment requires a complex installation process.

2 Motivation

During the last years, advanced tools of informatics enable the recording and evaluation of great amount of data to meet the actual engineering need.

The present paper reports about the application of kinematic GPS to survey and track a moving cableway, in order to detect deviations of the position of the towers from the planned layout. The analyses of the results enable us to draw conclusions from geodynamic processes, like instability of the ground on which...
the tower are erected. On the basis of this discrete punctual information it is possible to monitor the dynamic of a large area.

3 Measurements

3.1 The measurement set-up

A special device has been projected to fit a GPS receiver on the top of a cabin of the cableway to be measured. The antenna is positioned at the same level as the cable and at a horizontal distance of 46 cm from the inwards edge of the cable.

The theoretical connection between the two ends of the cableway is a straight line. To accommodate this fact, the position of the cable at the start and at the end station has been projected and fixed on the ground, to be measured afterwards. The connection line between these points represents the theoretical run of the cable.

In order to permit an independent verification of the kinematic GPS observations some points along the cable have been projected on the ground and fixed, to be measured afterwards.

![Fig. 1 Measurement set-up](image)

3.2 Data gathering

The cabin with the active GPS receiver (rover) has started from the station uphill, moved down to the station downhill and back to the starting point. The carrying and drawing cable was moving at a speed ranging in 0.1-1.5 m/s. The data storing interval of the receiver was set to 2 seconds. That means that every 0.2 m up to 3 m the position of a point has been registered. Consequently, the storing device of the GPS antenna stored 3D co-ordinates for approximately 2000 points.

Two reference stations providing additional information for tracking the cabin, have been placed in the surroundings of the installation. The measuring modus of the rover was set to “kinematic on the fly”. This is a variation of the kinematic technique and meets the requirement of initialising at the start or when the number of observed satellites drops below four. Therefore the initialisation process and the solution of the ambiguities take place during the post-processing. It means a loss of information, for the interference by the receiver is regained retrospectively.

![Fig. 2 Cabin with rover on the move](image)
With the beginning of the GPS session, a stopwatch has simultaneously been started. Every time the cabin passed a tower the corresponding time was noted. Considering that the storing device of the GPS antenna uses the record time as point identification, it is possible, comparing them with the time measurement, to determine the position of the towers, which support the cable.

The positions of the control points, which have previously been fixed on the ground, have been measured with directions and distances from known points as well as with static GPS sessions.

4 Evaluation

4.1 Adjustment

The acquired observations have been revised and reassessed. Afterwards the available measures have been integrated in a joint adjustment, where with homogeneity in terms of orientation and reference of the net was warranted. The output of this first compensation represents the base for the following analyses.

Due to the particular form of the device fixing the GPS antenna on the cable the registered coordinates were 46 cm outside the cable. In order to have coordinates referable to the actual position of the cable, a transformation, based on the predetermined points by both ends of the cableway, has been computed. The goal of a successive compensation was to accommodate the fact that between two successive towers the ground plan of the cable has to be a straight line. That the geometrical condition has been introduced into the functional model means fictive observations. These additional entries were based on a local coordinate system, whose abscissa connected two successive towers and the ordinate values were set to zero. The so defined condition forces the real GPS observations to join the straight line, minimising the effect of externalities like wind and interferences by the receiver.

4.2 Results

The results of both adjustments (with and without linearity condition) have been compared with the control points, and defined as the distance between the two carrying cable ducts (up and down). Table 1 and Table 2 summarise the planimetric comparison.

| Points identification | A1-K1  | A2-K2  | A3-K3  | A4-K4  | A5-K5  | A6-K6  | A7-K7  | A8-K8  | A9-K9  | A10-K10 |
|-----------------------|-------|-------|-------|-------|-------|-------|-------|-------|-------|--------|
| Fix point-Point on the cable | Without conditions/mm | With conditions/mm |
| Fix point identification | -6.9 | 1.8  | -11.7 | 8.6  | -4.4  | 17.3  | 9.0  | 11.3  | -3.9  | 8.9    |
| Average               | 3.0 ± 9.4 | 2.0 ± 9.3 |

Table 2 Comparing the gauge at each tower, target value \( D = 4.761 \text{m} \)

| Tower identification | Without conditions/m | With conditions/m |
|----------------------|----------------------|-------------------|
| Station downhill     | 4.754  | 4.754  |
| 2                    | 4.772  | 4.770  |
| 3                    | -      | 4.750  |
| 4                    | 4.767  | 4.753  |
| 5                    | 4.744  | 4.756  |
| 6                    | 4.750  | 4.751  |
| 7                    | 4.754  | 4.749  |
| 8                    | 4.753  | 4.749  |
| 9                    | 4.744  | 4.747  |
| 10                   | 4.757  | 4.742  |
| 11                   | 4.745  | 4.749  |
| 12                   | 4.742  | 4.741  |
| 13                   | 4.748  | 4.748  |
| 14                   | 4.753  | 4.755  |
| 15                   | 4.766  | 4.765  |
| Average              | 4.752 ± 9.03mm | 4.753 ± 7.410mm |

Taking the linearity condition into consideration, the points fit the target value better. This method allows both to detect outliers and to minimise their influence.

The influence of the linearity condition is not sensible in this case, but through it, it was possible to calculate the gauge by the tower No. 3, where the actual tower was identified with an outlier.
As GPS furnishes 3D coordinates, some analyses concerning the course of the height of the cableway are possible. On one hand it is possible to draw a side-face of the cableway, which emphasises the position of the tower (in Fig. 3). On the other hand it is possible to integrate this information in a GIS, e.g. about the obstacles for the aviation. Therewith, given the suitable software, 3D scenery representing the landscape and the cableway are computable (in Fig. 4).

Fig. 3 Side-face of the cableway

5 Conclusion

From the described project, the following conclusions can be drawn:

1) Methods of satellite geodesy can be applied to determine the actual position of the axis of the cableway. As a consequence, also the deviations of the position of the tower, due to geodynamic process or mechanical movement, can be detected.

2) Compensation of GPS observations brings about better results, when a condition of linearity is taken into account.

3) Conditions of linearity allow to detect outliers.

4) The method is reliable and precise.

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