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Determining the inclination of tall chimneys using the TPS and TLS approach

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ABSTRACT

In order to ensure safe operation of tall industrial chimneys their verticality needs to be accurately monitored. Vertical plumbing, the classic geodetic procedure for detecting the inclination has certain drawbacks and can be replaced by modern technology if necessary. In this article we are going to propose a more general and rigorous procedure, which includes measurements that result in point clouds, and explain the processing of this type of data. In our case study we used two types of modern geodetic instruments: the most accurate total station (TPS) Leica TS30 and the terrestrial laser scanner (TLS) Riegl VZ-400. Data acquired with these instruments were fit to a cylinder using the least squares adjustment and the results were compared. The article points out the differences between the used technologies as well as the differences between the results. During the study certain questions arose and we tried our best to explain and solve them. These included: the outlier detection and removal, the influence of large amounts of data on processing time and accuracy estimates, the influence of angle of incidence of laser beam on the chimney's inclination. In the end the deviations from the best fitting model were investigated. The article represents a comprehensive review of the use of modern geodetic technology for solving important engineering monitoring tasks.

1. Introduction

Tall industrial chimneys may potentially become dangerous for their surroundings. The forces that emerge as a result of their own weight and the effects of external forces such as wind, earthquakes in conjunction with the foundation and construction may lead to them slanting. Excessive inclination can lead to a permanent deformation of the chimney's construction, or, in the worst case scenario to the chimney collapsing. All of this makes the inclination information important.

European standards prescribe the maximum permitted horizontal offset of the steel circumference of a standalone chimney [1]. The horizontal offset is an outcome of the chimney's inclination. In classical surveying the inclination of the chimney can be measured by the use of optical theodolites that compare how parallel the vertical surface of the object is with the vertical line in the telescope's reticle. This method is known as eccentric plumbing. The offset of the edge of the object's surface from verticality can be easily measured by a tape. Although this method is extremely precise it can determine the inclination only in a single direction. In order to determine the maximum value of the inclination and its direction, the method must be repeated from at least from a different, preferably perpendicular, direction. Other method was developed by Onu et al. [2], where the inclination of tall buildings such

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as chimneys can be determined using geodetic measurements and computations algorithm with circular sections. The disadvantage of first method (plumbing) lies in the fact that the chimney usually does not have the shape of a cylinder but that of a cone and the major disadvantage for both mentioned methods the inaccessibility of points on the chimney's surface. This two method also demands a large amount of field work. As alternative to the conventional geodetic measuring methods a photogrammetric approach was introduced by Zheng et al. [3] where the chimney's deformation was presented by centre displacements of separate chimney's sections.

Our approach is based on the modelling of the object using measured points directly on its surface. This problem can be solved by an innovative method, the modern geodetic surveying instruments, which allow us to remotely (reflectorless) determine the positions of the points on the object's surface. Usually these instruments can perform the measurements in the so-called automatic scanning mode of a predefined area using a predefined raster density. We used two different terrestrial surveying measuring systems: the terrestrial positioning system (TPS) – total station Leica TS30 and the terrestrial laser scanner (TLS) – Riegl VZ-400. With the measured point clouds on the object's surface the object can be mathematically modelled as a geometrical body in a coordinate system determined by station points from which the inclination of the chimney's central axis can be calculated.

Next, the method is theoretically described and practically tested on two chimneys in the Brestanica (Slovenia) thermal power plant. One of the important parts of this article is the comparison between the TPS and TLS approach. The advantages and disadvantages of the used surveying methods are discussed.

2. Methodology

2.1. Data acquisition and pre-processing

The geometry of the chimney should be optimally defined. The modelling is performed with the use of measured points on the chimney's surface in a Cartesian coordinate system. Both instruments (TPS and TLS) are used to obtain these coordinates with the polar surveying method. The horizontal direction, zenith angle and slope distance are measured to each point. In order to obtain the Cartesian coordinates of the measured points the position and orientation of the instrument must be known.

The TPS instrument can be horizontally set to a precise point within the geodetic network (see Section 3). When we measure the horizontal direction towards another point, the position and orientation of the instrument can be fixed.

On the other hand, the TLS instrument cannot be set to a specific point, nor can it be set horizontally. In order to georeference the TLS instrument one needs to provide at least three known points and calculate the transformation parameters between the scanner's own coordinate system and the referential coordinate system. Once this is performed all TLS measurements can be transformed into a common reference coordinate system.

The calculation of the coordinates from raw terrestrial measurements is a common geodetic procedure and will not be discussed in this paper. Any interested reader should refer to [4] for details on TLS registration and transformations. Further in the article point coordinates will represent the measured values in the adjustment procedure for determining the parameters of the chimney's mathematical model. The calculated parameters of the mathematical model allow us to calculate the position and orientation of the chimney's axis.

Various errors can occur during the measuring process. As the data acquisition in the scanning mode is fully automated it cannot be supervised point by point. Therefore, it is possible that some points do not lie on the object's surface. This can occur due to different obstacles such as e.g. fences, stairs (see Fig. 1). Such points would represent gross errors and need to be removed. When dealing with a small set of measured points this can be performed manually, however if we are dealing with a large set of points, so-called point clouds, numerical methods can be more appropriate. In our case the RANSAC algorithm [5] was effectively used to mathematically model the surveyed object.

2.2. The calculation of the inclination and its accuracy

We assume that the chimney's shape is symmetrical about its central axis. Despite the fact that the chimney

Fig. 1. Industrial chimneys in the Brestanica thermal power plant.