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A simplified procedure of metrological testing of the terrestrial laser scanners

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ABSTRACT

This paper presents a simplified test procedure of the terrestrial laser scanners (TLS) accuracy investigation by the general criteria of the ISO17123 standard. The proposed procedure covers investigation, analysis and accuracy estimation of the TLS system in the controlled environmental conditions. This procedure is mainly developed based on the model of a system calibration and network design procedures. Metrological Laboratory of the Faculty of Civil Engineering in Belgrade is customized for TLS testing. The accuracy investigation of a commercial TLS has been performed. The accuracy of the resulted point cloud, which is indirectly represented by the coordinates of the acquired control points, is determined. Beside the analysis of the residuals of the 3D spatial transformation, the analysis of the true and the measured distance differences is also performed. The results show that these two approaches give the statistically same uncertainty indicators. Precision of the target recognition and influence of the unlevelled point cloud to the TLS centering error is also analyzed. Normality tests are used to determine whether a data set is well modeled by a normal distribution or not before testing of hypothesis for the variances. By varying the number of the control and check points it is shown that increasing the number of the control points more than three well distributed is not relevant for significantly higher transformation accuracy. On the basis of the conducted spherical orientation analyzes it can be concluded that the global orientation of the error vectors follows the laser beam direction due to relatively short distances. The most important result related to investigated TLS is that this particular sensor must be used only by indirect georeferencing experiment design.

1. Introduction

Despite the reason that terrestrial laser scanning technology is used in geodetic engineering for more than a decade, the validated methodology of the experiment and data processing design is still missing. In addition, there is still no standardized declaration of the terrestrial laser scanners characteristics in terms of the accuracy, precision and data quality. Some other features and technical descriptions sometimes cannot be reliably interpreted. Therefore, comparison of the scanners of the different TLS manufacturers and even models of the same manufacturer is not very convenient.

A standardized procedure for testing the accuracy of TLS does not yet exist. Standard ISO17123-2012 in eight chapters describes the procedures for testing geodetic sensor systems, such as levels, total stations and GNSS (Global Navigation Satellite System) sensors. It was released in several versions between 2001 and 2012. With the

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publication of the latest ISO standard for the GNSS field measurement systems in Real Time Kinematic (RTK) measurement method in September 2007, TLS remains the only geodetic sensor without standardized accuracy testing procedures [10,4].

In order to provide appropriate and practically suited testing procedures for the specific sensor systems, ISO 17123 defines two test types that vary in complexity, i.e. the simplified testing procedure or the full testing procedure. The simplified testing procedure investigates the agreement to a given deviation with a minimum time for measurements and evaluation of the results. The computed uncertainty is based on a relatively small sample of the measurements and the significance of these values is quite limited. On the other side, the full testing procedure requires a larger sample size. Computed standard deviations are more significant for the evaluation of the measurement precision and accuracy. Due to higher redundancy of the measurements, the statistical testing of the results is more reliable. Also, the required calculation equations are well specified [10].

It is important to distinguish between the procedures of the accuracy testing and the calibration of the TLS. The first term refers to the accuracy testing in order to obtain specific quantitative indicators of uncertainty, while the second includes the correction of the measurement results by determined size of the specific systematic error influence. The basic problem is that the TLS still represents a so-called black-box with unknown calibration model applied by the manufacturer. Researchers or users cannot neutralize them. Also, they cannot implement the corrections of the observed spherical coordinates directly to the instrument, but rather indirectly, correcting the plane coordinates using third party routines. In that case, they face a problem of the memory limits of the typical programming tools and data formats and, finally, with incompatibility of the corrected data with the original manufacturer's software during the further processing of scanned data.

The first papers on the accuracy testing and calibration of the TLS are published in 2000 [20,21]. Various contributions to the TLS calibration methodology were given in the past. Procedures of the so-called system calibration and additional parameters estimation were presented in [3,8,9,19,22,27–29,33,37]. The TLS components calibration is given in the [34]. Number of authors dealt with the TLS accuracy testing. Some studies focus on the accuracy of a particular TLS [6,23,15], while the few involved comparing the accuracy of different TLS [16,26]. Beside the accuracy investigation, the contribution in more objective TLS specification is given in [42] by introducing different quality parameters such are geometric truth, measurement speed and achievable range. Field testing procedures of TLS are proposed in [11] as a possible basis for a future ISO test standard. The latest field testing procedure has been driven by the DVW (German surveyors association) to issue an instruction leaflet for practical TLS users [42].

The TLS axis errors are analyzed in [15,24,34]. The influence of the specific characteristics of the TLS system to the data noise is analyzed, such are the contribution of the laser beam incident angle to range noise [35,36], or characteristics of the scanning object [2,12,14,18,25,40] and laser propagation environment [13,41] to the geometric uncertainty of the object modeling. The TLS orientation errors based on spherical statistics and 3D graphics are analyzed in [4]. The design of those experiments depends on the methodology of the TLS accuracy testing. The experiments are mainly carried on more or less customized indoor or outdoor facilities.

2. Testing methodology

The main objective of this simplified testing procedures is to determine the accuracy of the TLS observations and the resulted point cloud, which is generally represented by the coordinates of registered scanner targets. In addition, the precision of the target center recognition and the influence of the unlevelled point cloud to the TLS centering error is also analyzed.

2.1. Test site and network configuration

The approach of the accuracy testing experiment is chosen by the model of TLS system calibration and a network design [28]. Precondition for determining the positional uncertainty of the scanned point cloud is existence of the control network, with the coordinates determined by a more accurate method (Table 1). Those coordinates can be considered as conditionally true when the influence of their uncertainty is insignificant for investigating the TLS accuracy. Also, it is necessary to provide the sufficient number of the scanner targets with their appropriate spatial distribution [38].

The two approaches could be used to determine the size of the deviation between the scanner acquired and the conditionally true coordinates. The first approach is based on the spatial transformation model from the scanner to the control network coordinate system. A single error vector is dependent on the control points selection used in the parameters estimation, while the standard error reflects the global uncertainty. The alternate solution of the scanner accuracy estimation assumes the analysis of the distances between the identical pair of the scanner targets acquired by the scanner and derived from the control points coordinates. The size of the points coordinate error is calculated by the error propagation law. The estimates of the error vectors are dependent on the desired pairs of the targets/control points used in the single distance difference.

The TLS manufacturers publish the scanning accuracy related to the scanning distance. For instance, Leica Geosystems – 50 m, Faro – 25 m, Zoller + Frühlich – 50 m and 100 m, etc. In the geodetic engineering the scanning distance varies from a few meters to several hundreds of meters. A testing site should be suited to the typical scanner accuracy investigation in the terms of its size and the position of the observation pillars. This is a potential problem since the sites for geodetic sensors testing are designed for testing the instruments such as total stations, GNSS sensors or levels [19]. Thus Metrological Laboratory of the Faculty of Civil Engineering in Belgrade defines only