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ПРИМЕНЕНИЕ НАЗЕМНОГО ЛАЗЕРНОГО СКАНИРОВАНИЯ В СОВРЕМЕННЫХ УСЛОВИЯХ

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Аннотация: В настоящее время метод наземного лазерного сканирования (НЛС) применяют во многих областях инженерной геодезии. В основном НЛС используют в целях технического обслуживания зданий и для обнаружения смещений их структурных элементов, а так же при мониторинге различных технических объектов. Данный метод находит все большее применение в горном деле для получения более подробной информации о состоянии выработок, проходов и шахтных подъемников. Кроме того, НЛС используют в цифровом топографическом моделировании. Метод НЛС постоянно совершенствуется. В данной статье дается краткое описание НЛС и приводятся примеры применения этого метода. Описан пример проведения обмеров исторического здания водонапорной башни в г. Вроцлав (Польша). Полученные данные использовали при разработке подробной архитектурной и строительной документации по описанию внешних стен здания. Еще один пример применения НЛС касается исследований деформаций гидротехнического сооружения, а также контроля эксплуатационной способности тонкостенной конструкции. Подчеркивается универсальный характер техники наземного лазерного сканирования и возможность расширения области его применения для обмеров крупных и мелких объектов.

Ключевые слова: геодезические измерения, наземное лазерное сканирование, архитектурно-строительная документация, горизонтальные смещения, тонкостенная конструкция.

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Modern applications of terrestrial laser scanning

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Abstract: Nowadays there are a lot of applications in many branches of engineering geodesy where the Terrestrial Laser Scanning (TLS) is applied. It is mainly used for inventory measurements and detection of buildings displacements. The mentioned method is also commonly used to monitor engineering objects. The TLS is increasingly used in mining to obtain detailed data on mining excavations, passages and hoist towers. In addition, TLS allows creating digital terrain models. This method is still being improved. In this paper, the short characteristic of TLS is included and some examples of innovative application are presented. The first example describes the measurement of a historical building, which is the water tower in Wrocław (Poland). The obtained data were used to prepare a detailed architectural and construction documentation of external walls of the building. The other examples of TLS applications concern the investigation of deformations of a hydrotechnical facility and the control of verticality of a slender structure. The article emphasizes the universality of the laser scanning technique, which can be used to measure large and small objects.

Key words: geodetic measurements, Terrestrial Laser Scanning, architectural–construction documentation, horizontal displacements, slender structure

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Introduction

Development of measuring techniques allows surveyors to automate the process of displacement monitoring and also increases the accuracy of the results due to new generations of instruments. Modern measurement techniques (likemotorized tacheometry or close-range digital photogrammetry) allow describing the geometric shape of a structure and detecting disturbing changes in the structure's shape. However, the Terrestrial Laser Scanning (TLS) is the most popular measurement method, which is widely used in engineering surveying. Nowadays, this method enjoys different applications such as measurement of displacements and deformations, control of the building's behavior with the design status, inspection of buildings or preparation of architectural–construction documentation. The TLS is increasingly used in mining. It provides detailed data on mining excavations, passages and hoist towers. An example of the application of the laser scanning is the calculation of the cut or fill volume of ground masses in [1]. The mentioned method is desirable in this case, because it allows obtaining the results in inexpensive way, as well as in a short time and with the required accuracy. Another example of using the TLS is determination of the surface deformation, especially in the shallowly located mining excavations as is described in [2]. In addition, laser scanning is becoming increasingly used in tunnel construction, mainly for creating documentation. However, an important aspect is the possibility to make a 3D model of the tunnel being surveyed, which allows checking its geometry accurately [3]. In this paper, the examples of using TLS to various engineering cases are presented.

Basics of Terrestrial Laser Scanning

TLS is a measurement technique to measure the distance to the object as well as the horizontal and vertical angles at the same time. This method uses electromagnetic radiation that gets to the examining object in the form of a wave, which could be dispersed, absorbed and partially reflected from the object's surface. Scanners can be divided in to three types: pulse scanners, phase scanners and triangulation scanners. The first type offers the largest measurement range, but phase scanners can measure more points per second with better accuracy for short distance [4]. The best precision of the resulting coordinates can be achieved by the triangulation scanners, but the distance between the instrument and a measuring object cannot be larger than a few meters [5]. This method allows measurement of even a million points per one second, which represent a geometric shape of the object. The cloud of points is a result of scanner measurement. Every single point has its own x, y, z coordinates.The obtained point cloud can be presented in three different coordinate systems: in the local scanner coordinate system (SOCS), in the project coordinate system common for several scanner stations (PCS), as well as in the geographic coordinate system (GCS) [6]. The obtained cloud of points enables creating a 3D model of examined object. The measurement can be made from various scanner locations. The positions of the scanner should be arranged so that the entire object can be measured. The point clouds obtained from different scanner stations are combined in the registration process, with the use of special signalling targets during the measurement. These targets should be regularly placed around the object [7]. The second method, used to combine the clouds together, is the so-called cloud-to-cloud method. During the measurement, colour of the object (on the basis of photos), strength of the laser beam reflection (intensity) and sometimes the temperature of the object (thermovision) are registered for each point. The TLS technique saves a lot of time during the measurements, but also requires a special software and qualified people who can use it to process obtained data. Currently, the laser scanning is more and more frequently used in various fields, while its applications mainly include the monitoring of engineering objects and inventory measurements of large structures.

Applications of Terrestrial Laser Scanning

TLS of the water tower

The first example of using the TLS is the measurement of the water tower, which is one of the representative historical buildings in Wrocław. The water tower was measured by means of the Leica ScanStation C10 scanner in 2016, as a part of the engineer thesis [8]. Because of irregular form and unusual geometry, this technique was the most proper for this object. Measurement works included: field reconnaissance, project of geodetic control network, stabilization of the geodetic points, measurement of the geodetic network and laser scanning of the building. The designed angle-linear network consisted of nine points located around the tower. The geodetic network was measured by means of the total station TOPCON GPT-3005LN. The water tower was scanned from sixteen temporary scanner stations. From

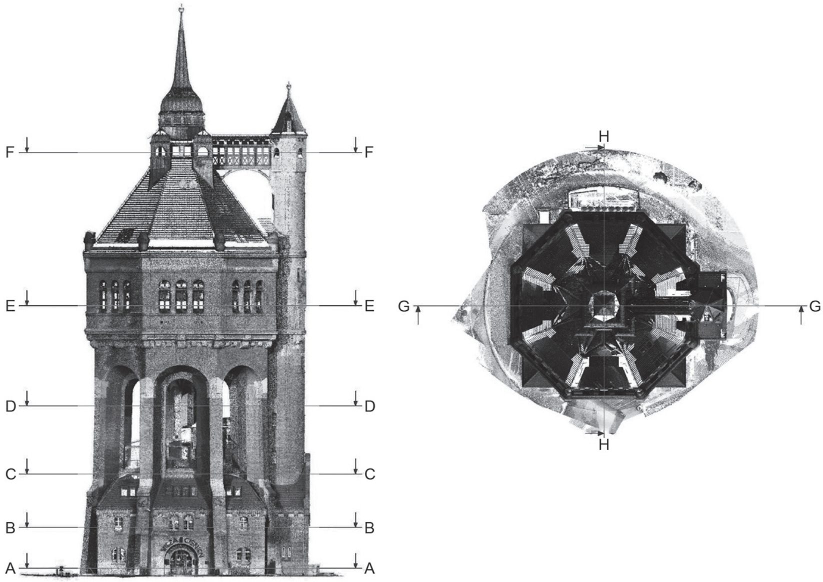

Fig. 1. Localization of horizontal and vertical cross-sections [9]
Рис. 1. Локализация горизонтальных и вертикальных сечений [9]

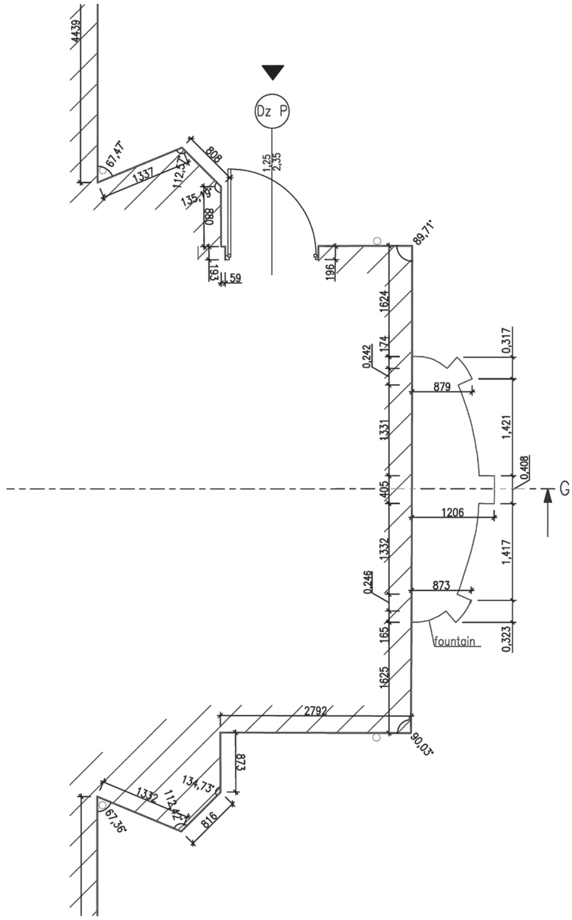

Fig. 2. Fragment of horizontal cross-section A-A (at the level of 0.30 m above ground) [9]
Рис. 2. Фрагмент горизонтального сечения А–А (на уровне 0,30 м над землей) [9]

each of them, the minimum five of special signalling targets were observed. The targets were placed at nine geodetic network points. The density of the scans was about 1 cm [8]. The obtained registration precision of the scans, based on the control network, amounted to 3 mm. In January 2019, this point cloud was used to prepare a detailed architectural and construction documentation of external walls of this object [9]. The documentation was prepared in the following software: Cyclone, CloudCompare and AutoCAD. The first part of the works included selection of horizontal and vertical cross-sections (Fig. 1), point vectorization and technical paperwork. The results were six horizontal and two vertical cross-sections. Figures 2–4 present fragments of these documentations. The second part includes making five orthoimages of the elevations (Fig. 5). Due to high precision, the performed drawings constitute a proof of the usefulness of this measurement technique application in the scope of inventory of historic buildings.

The process of creating architectural and construction documentation of historic buildings should be prepared in accordance with the norms and standards in

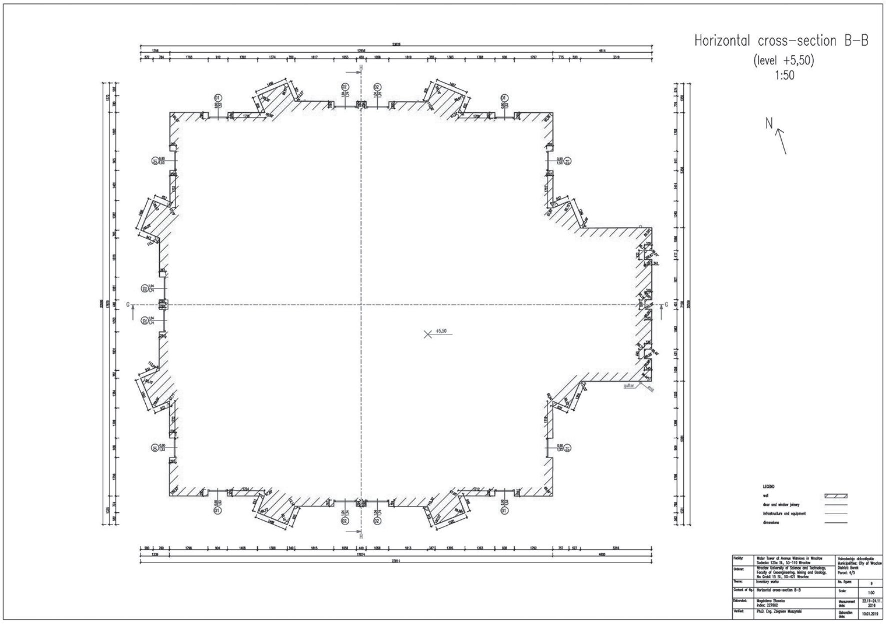

Fig. 3. Horizontal cross-section B-B (at the level of 5.50 m above ground) [9]
Рис. 3. Горизонтальное сечение Б–Б (на уровне 5,50 м над землей) [9]

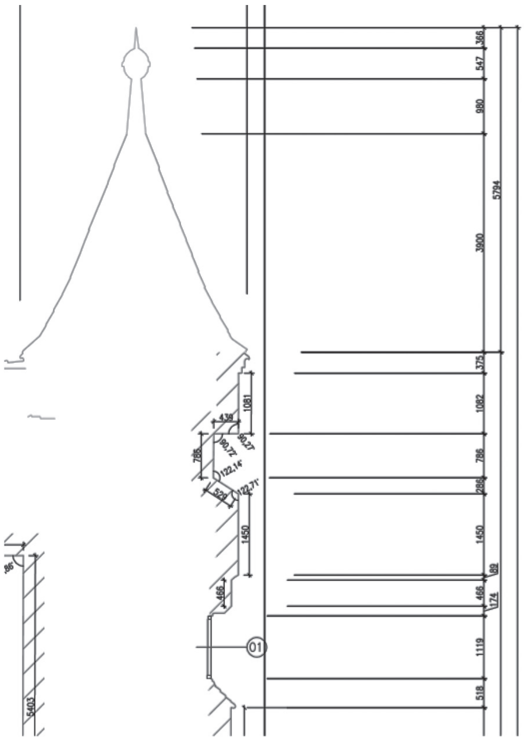

Fig. 4. Fragment of vertical cross-section G-G [9]
Рис. 4. Фрагмент вертикального сечения Г–Г [9]

force. Due to the specific features of works related to the measurement of the object and the preparation of the documentation, shortening the time of the documentation cannot consist only in increasing the number of contractors. One of the reasons for this is the need to complete the various stages of the work in the right order [10].

The laser scanning method can be also used for a technical analysis of an object as well as for historical analysis, by comparing the results of the laser scanning and traditional methods from previous years. The article [11] presents a comparison of the 3D model of the radio tower and previous measurements made over the years. During the comparison, differences between the historical documentation and the result of the measurement with a laser scanner were detected.

TLS of the hydrotechnical objects

Determining the displacement requires measurements with very high accuracy but there are some structures for which the precision of laser scanning is sufficient (e.g. for large dams). Terrestrial laser scanning enables to obtain a fully metric, three-dimensional model of a measured hydrotechnical object in a relatively short time. However, application of this method allows for registration of the condition of the entire structure, despite of relatively small accuracy of determining the position of a single point. Mounting additional targets on the examined structure enables to detect displacement of the control points with a better accuracy. The paper [12] present an example of determining horizontal displacements of the hydrotechnical objects using the products from laser scanning in comparison to classical techniques of measurements for this issue. It is also possible to integrate various measuring techniques. In this example, the measurement network required the current adaptation for successive stages of the modernization works. The suggestion is to make a registration based only on geodetic points for which the coordinates were determined by means of precise total station's measurements. Undoubted advantage of TLS using is the possibility of controlling the changes of the structure by comparing two point clouds taken from different time periods. If the reference system is the same for both point clouds, the values of quasi-displacements can be determined.

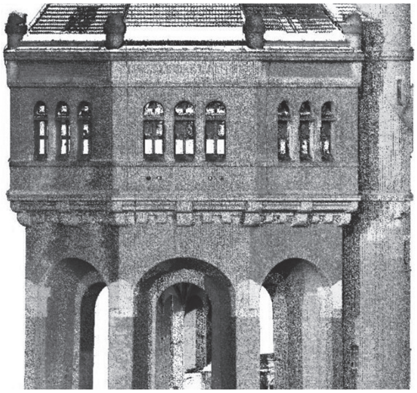

Fig. 5. Fragment of orthoimages of elevation (front side of the tower) [9]

Рис. 5. Фрагмент ортоизображения вертикальной плоскости (передняя сторона здания водонапорной башни) [9]

In practice the calculation of displacements includes a lot of components: identification geotechnical processes that may affect the object, data acquisition, use of different technologies of surveying, contribution of new technology of measuring or data processing and expert input. All these cases need to be rightly managed to enhance operations and get desired results. The authors in work [13] show the way to deal with management of geotechnical data and application of improved knowledge and advanced technology to enhance the management of geotechnical processes.

TLS of the slender structure

An extremely important aspect of inspection of slender objects is the stability of their foundation, because it affects subsidence of the object. Therefore, when designing foundations, it is necessary to carry out geotechnical research to ensure foundation stability. This problem was described in details in article [14]. The process of measuring the geometry of a structure depends on the availability of the object. When the scanner is located near a very tall object, the top of the tower is scanned at a steep angle, which may generate inaccuracies. The paper [15] presents the application of the TLS of the Shabolovka Radio Tower in Moscow. The mentioned object has a lattice construction and is empty inside. In order to obtain detailed data of geometry of the structure, it was necessary to organize scan positions at service platforms on different levels inside the tower.

The article [16] describes the use of scanning to control the verticality of the concrete industrial chimney with a height of 120 m. In 1996 and 2004, the verticality of the chimney was checked using classical method (surrounding tangents method measured by means of total stations). For each of the previous measurements, the different measurement levels on the chimney were measured, so it was impossible to directly calculate deviations between these years.

In 2013 the geometry of the industrial chimney was controlled using terrestrial laser scanner. Due to adverse conditions, the obtained point cloud was incomplete and required time-consuming cleaning. Despite of correctly performed measurement, the accuracy of calculated deviations of the chimney's axis from vertical was relatively small, although satisfactory in this case (no worse than 30 mm).The biggest advantage of laser scanning is possibility to obtain detailed data about geometry of the structure. In the discussed case, this allowed comparison of the data of the two previous measurements with the results of scanning.

Integration of TLS and other measurement methods

In addition to the above-mentioned applications, laser scanning is also used for dimensional inspection of manufactured large-scale components. In the article [17] a scanner was used to measure the manufactured component, and then the measurement results were compared with CAD documentation. The use of this method produced better results while saving time.

The aim of the work [18] was to obtain more accurate and detailed images for monitoring quarries. The laser scanning data in the study were used to supplement the photogrammetric method. The reference of photogrammetric images was a three-dimensional model obtained with TLS method.

Drones are increasingly used in engineering geodesy to acquire large amounts of data about an object. The paper [19] describes the use of Geoscan 401 unmanned aerial survey system for magnetic field analysis. The results of the measurements of Geoscan 401 are also used to create 3D models. Comparison of data from aerial and ground measurements (TLS) allows determining the usefulness of the aerial survey system and possible integration of data from two sources.

Conclusions

The TLS is a constantly developing measurement method which allows measuring things and object very fast. This technique gives the possibility of continuous monitoring of changes. This ability is particularly important when the measurement includes engineering objects, which are exposed to destructive environmental factors. Another important aspect in favor of the TLS is the non-contact measurement of objects in the danger zone (e.g. collapse threat), without endangering the health or life of the person performing the measurement.

In the world of collecting data about almost everything, laser scanning is a useful technique, although has some limited accuracy. The accuracy of the laser scanner data depends on many factors, such as the type of the scanner, weather conditions, characteristics of the object being scanned (surface color and texture), as well as the angle of laser beam incidence. The mean error of 3D position for a single point ranges from 1 to 6 mm, depending on the above mentioned factors. This accuracy is usually satisfied for reconstructing of geometry of the entire objects (e.g. inventory of historic buildings) and for engineering object monitoring. The obtained data from laser scanning give a lot of opportunity to use them in a different way. This method can be widely used to inspect buildings or prepare the architectural–construction documentation, as it was shown on the example of the water tower. The other presented examples confirm usefulness of TLS in determining the displacements of objects or verification of geometry of industrial chimney. Products of TLS could be also useful for analyzing factors affecting the examined object.

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ИНФОРМАЦИЯ ОБ АВТОРАХ

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