TECHNICAL SCIENCES
Abbrev.: Techn. Sc., 2011, 14(1)

EVALUATION OF POSSIBLE APPLICATION OF TERRESTRIAL LASER SCANNER – SCANSTATION IN VERTICAL DISPLACEMENT MEASUREMENTS

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K e y w o r d s: terrestrial laser scanner, vertical displacement.

A b s t r a c t

Author of the article conducted empirical studies to show the usefulness of the laser scanner in displacement measurements. Vertical displacements were measured on a tester that was specially contracted for that purpose. The test measurements were carried out by applying different methods and different instruments, i.e., the precise leveler, the total station applied with the reflector of without it and ScanStation laser scanner. The test results show great potential for laser scanning in determining the vertical displacements even of millimeter values. The paper also presents briefly how to use laser scanning in surveying measurements and a special attention was paid to some of the parameters characterizing accuracy of the laser scanning.

OCENA MOŻLIWOŚCI ZASTOSOWANIA SKANERA LASEROWEGO SCANSTATION DO POMIARU PRZEMIESZCZEŃ PIONOWYCH

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S ł o w a k l u c z o w e: skaner laserowy, przemieszczenia pionowe.

A b s t r a k t

Autor artykułu przeprowadził badania empiryczne mające na celu pokazanie przydatności skanera laserowego w pomiarach przemieszczeń obiektów inżynierskich. Na specjalnie do tego celu skonstruowanym przyrządzie pomiarowym dokonano pomiaru przemieszczenia pionowego. Wykorzystano różne instrumenty i techniki pomiarowe. Do wyznaczenia przemieszczenia pionowego zastosowano niwelator precyzyjny, tachimetr elektroniczny z funkcją pomiaru z reflektorem i bez oraz skaner laserowy ScanStation. Wyniki testu wskazują na duże możliwości skanowania laserowego w wyznaczaniu przemieszczeń pionowych i pozwalają na wychwycenie ich milimetrowych wartości. W pracy przedstawiono sposoby zastosowań skanowania laserowego w pomiarach oraz zwrócono uwagę na niektóre parametry dokładnościowe charakteryzujące skaner laserowy.

Introduction

Laser scanning was introduced in Poland in 2003. Since this time it became a subject of research for many specialists, especially for surveyors. Until then, the only way to measure inaccessible places was based on photogrammetric methods. This method was accurate, however, its range was rather small. Another disadvantage was, and still is, a long time of elaboration of the data. The advantage of the laser scanning is that we get 3D coordinates during the measurements at once. It is also possible to analyze results just after the measurements. The result, namely the point cloud is a set of vectors and all the measured points have 3D coordinates. Thus, it is possible to compute distances, angles or azimuths between them. From the practical point of view, it is important to know the accuracy of the measurements. Such accuracy depends on the instrument applied among others. It also shows the possible application of the laser scanner, namely the surveying problems where scanning accuracy is sufficient. One of such problems is analysis of deformation or displacement of engineering structures. Such displacements may have different sources and properties, and also different absolute values, which influence the choice of proper surveying instruments. The accuracies that are given by the scanner producers, encourage to apply laser scanners to measure even very small, millimeter displacements, Therefore, it seems important to test such accuracy in practice, especially that results of similar analyses are very promising (TOURNAS, TSAKIRI 2008, LOVAS et al. 2008). The present paper shows possible surveying applications of laser scanning and presents practical tests of use of the laser scanner in vertical displacement analysis.

Application of laser scanning

Laser scanning can be regarded as a new technique of inventory of engineering structures or measurement of ground surface. It can be use, for example, in architectural inventory of historical objects (WONG 2009), a single buildings (HEJBUDZKA et. al. 2009), group of engineering structures (GORDON et al. 2003), steel constructions (ĆMIELOWSKI et al. 2009) or water structures (ALBA et al. 2006). Laser scanning is used in mining areas where it is applied to measure outcrops, mine waste dumps and other by-products of mining activities (GEOFF 2008). It is also applied in archeology to inventory excavations (MOORE, FORSYTHE). It is often applied to measure equipment of refinery where direct measurements are usually impossible. Due to this technique one can measure all the points that are visible from the station of the scanner (FLOYD, SANDERS 2001). Laser scanner can also be a source of data for numeric model of terrain (BOJAROWSKI et al. 2008a).

There are two kinds of software that are necessary to work with a laser scanner. The first one controls the scanner during measurements, and the second one is applied to do basic operations on point clouds. One can obtain 3D models of complex structures, generate 2D pictures, model different shapes (pipes, lines or architectural elements) and fit them in a point cloud, find collisions, visualize objects, prepare animations etc. Laser scanner is therefore a good source of data for necessary documentation of buildings before renovation, and also in shape analyses of damage buildings. Wide application of the method in question is due to its accuracy. Some applications require a centimeter, while the others a millimeter accuracy. Therefore, it seems reasonable to develop this technique, especially in analyses of displacements and deformations. The angle and distance accuracies of laser scanners make possible of their application in surveying.

Lasers scanners are the next step in development of electronic tachimeters. Similarly to tachimiters, they compute 3D coordinates (X, Y, Z) of mwasured points on the basis of directly measured distances, vertical and horizontal angles. It is so-called refrectorless measurement, and the accuracies of both kinds of the instruments are also similar. However, laser scanner is much more quicker than traditional total stations. The impulse technique of measurements enable us to measure few thousands of points per second, while the phase one even up to 500 000. The disadvantage of laser scanner is its relatively smaller range (for the impulse scanner it is several hundred meters). Only few scanner have range about one kilometer. It is worth noting that the scanner range depends on a kind and color of a reflecting surface. The darker it is, the smaller range is. It follows strength of a reflected light ray, which is sometimes called the fourth coordinate. Beside accuracy and fastness of scanner measurements, there are several other properties that are important and required by the users. All such properties can be divided into three main areas. The first area, namely reliability refers mainly to accuracy and resolution. The second one consists of measurement speed, range and field of vision. The third area, functionality refers to size of a scanner, simplicity of running, and especially to the software (PUDŁO 2006, 2008). It is hard to decide which properties are the most significant. However, it is obvious that it depends on a kind of surveying problem or task that the scanner is applied for. For example, if a large area is measured then it is better to choose a scanner of longer range and lower accuracy. On the other hand, if a small details are measured then one needs a scanner of high resolution and accuracy. The speed of measurements seems to be less significant in such problems, however, this could change over time. Most of new potential scanner users would choose an „optimal" and most useful type of scanner, namely a scanner of relatively high accuracy and average (several hundred meters) range.

Accuracy of Laser Scaner

As it was already mentioned, the accuracy of a laser scanner is a very important parameter that determines usefulness of a scanner to certain surveying tasks. Boehler and Marbs (BOEHLER et al. 2003) presented some more significant factors that influence such accuracy. Now, let us remind them briefly.

Angle accuracy

These errors stem from the fact that a laser beam is deflected in two perpendicular directions by operating with high precision reflecting mirrors. Rotations of the mirrors cause some errors in the reading of horizontal and vertical angles, which results directly in errors of 3D coordinates. These errors are especially evident in the plane perpendicular to the direction of measurements.

Distance accuracy

Distance accuracy is very significant for general accuracy of the scanner. It can be described by two components: determination of the time of propagation of electromagnetic wave from the deflector to the target and back, and determination of the refractive index of electromagnetic wave in the air. Thus, it can be describe by the mean error in the following formula

$$m_D = D\sqrt{\left(\frac{m_\tau}{\tau}\right)^2 + \left(\frac{m_n}{n}\right)^2},$$

where:
m_τ – mean error of time propagation,
m_n – mean error of the refractive index n.

The component m_τ describes the accuracy of time τ, thus it describes all instrumental errors as well as errors that stem from operating the scanner. On the other hand, the component m_n represents the accuracy of the refractive index, which depends on the air temperature, pressure and humidity. Thus it describes errors that stem from the physical facility (PŁATEK 1991).

Effects of surface color

Different colors of the reflecting surface are sources of some additional systematic errors. For the primary colors one can compute corrections, however, the color of the reflecting surface is generally a mixture of the primary colors. Thus, it is almost impossible to correct the measurement properly. Usually, these errors are not so significant and do not influence the accuracy of 3D model obtained. To protect measurement results from these errors one can apply markers of the same color at the measured points.

Scanner resolution

Resolution is an important property of the laser scanner that describes its ability to detect small objects. It depends on two main factors: the smallest change of the angle between two consecutive measurements and the size of a laser spot.

Edge effect

The edge effect occurs when the laser spot reaches the edge of the measured object. Then, only a part of the electromagnetic wave is reflected and return to the scanner. The rest can be reflected by adjacent surfaces and give incorrect measurements. Incorrectly measured points can be close to the real edge of the object but sometimes the differences may reach even decimeters. This effect is particularly evident when a spherical or cylindrical objects are measured.

Effect of reflectivity

Laser scanner records laser beams reflected from measuring surface. The strength of the returning signal depends mainly on reflective abilities of the surface. Such ability is described by the albedo. Bright surfaces give a stronger return signal than dark ones. If the surface is dark and glossy one can expect no return signal at all. Effects of different reflecting surfaces depend on the spectral characteristic of the laser. The surfaces of the different albedos may result in systematic errors that exceed the standard deviation of measurement by several times. Thus, if the object measured is built of some different materials one should expect such big errors. To protect results from these large systematic errors, one can cover the object with a uniform material of the constant albedo for the measurement time (if it is possible, of course).

Research project

The idea behind the research project was to compare results of a laser scanning with more conventional methods of vertical displacement determination. I used the laser scanner Leica SkanStation and for the comparison I chose the electronic tachimeter Leica TC 705 and the precise leveler Carl Zeiss Jena Ni 002. I analyzed differences in determination of vertical displacements that were simulated by a specially constructed equipment (Fig. 1).

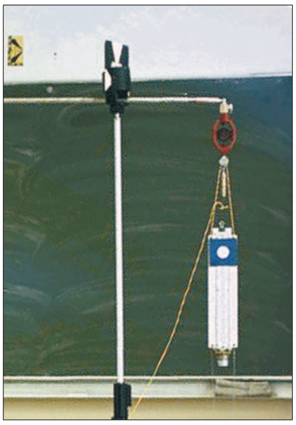

Fig. 1. Tester

Source: own development.

The tester was hung on an aluminum arm fastened to the wall just a few meters from the station. It consisted with a mini prism combined with a part of a precise leveling staff and a special shield HDS. During the tests, the tester was displaced in a vertical plane, and the values of displacements were measured by applying the instruments that were mentioned above. Thus, the displacements were measured using laser scanning, precise leveling or trigonometric method. The last method was carried out in two ways, namely with use of a prism and in reflectorless technique. In order to eliminate the vertical index error, the trigonometric method was carried out in two faces. The height differences *dh* were measured between the horizontal rotation axis of the telescope and the tester, which is a function of distance and a vertical angle. The displacements were also measured by precise leveling (accuracy of 0.2 mm/km of double leveling). These measurements were taken as a basis for comparison with laser scanning and the trigonometric method. The electronic tachimeter Leica TC705 has the following accuracy: angle accuracy 15^{cc}, distance accuracy 2 mm + 2 ppm (measurements with a prism) and

3 mm + 2 ppm (reflectorless). While for the laser scanner ScanStation, it is respectively 35[cc] for angle measurements and 4 mm for distances. The minimum change that can be measured vertically as well as horizontally is 1.2 mm.

The results of laser scanning were applied to model the shield HDS (Fig. 2) and to determine the center of the shield, namely a HDS vertex (dimensionless point) with 3D coordinates (*X, Y, Z*) (Fig. 3). The postrocessing was carried out by application of the software Cyclone v.5.6. I used only vertical component to determine the vertical displacements.

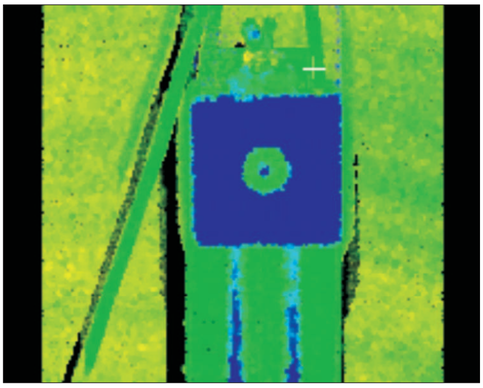

Fig. 2. Scan of the HDS target
Source: own development.

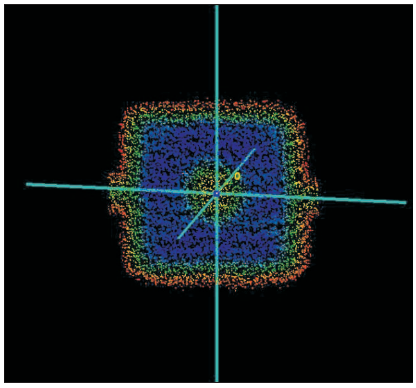

Fig. 3. Example of Vertex model upon the HDS target
Source: own development.

Table 1 presents the results of the measurements with the precise leveler, the electronic tchimiter (with a mirror and reflectorless) as well as the results of determination of the HDS shield vertexes.

Table 1

Measurement results

Level	Precise leveler			Total station measurement with a mirror [mm]			Total station measurement without a mirror [mm]			Terrestrial laser scanner [mm]
	loc. I	loc. II	average	dh loc. I	dh loc. II	average	dh loc. I	dh loc. II	average	
A	924509 317998	924343 317830	924426 317914	316	316	316	-8	-8	-8	143
B	930234 323729	930071 323569	930153 323649	288	288	288	-37	-37	-37	115
C	914095 307591	913940 307430	914018 307511	368	368	368	44	44	44	195

A, B, C - control levels
dh – height differences between the horizontal rotation axis of the telescope and the target

Table 2 presents the final values of the vertical displacements between the level *A* and both levels *B* and *C*.

Table 2

Value displacement

Displacement	Precise leveler [mm]	Total station measurement with a mirror [mm]	Total station measurement without a mirror [mm]	Terrestrial laser scanner [mm]
A-B	28.6	28.0	29.0	28.0
A-C	-52.0	-52.0	-52.0	-52.0

These results are also presented in Figure 4.

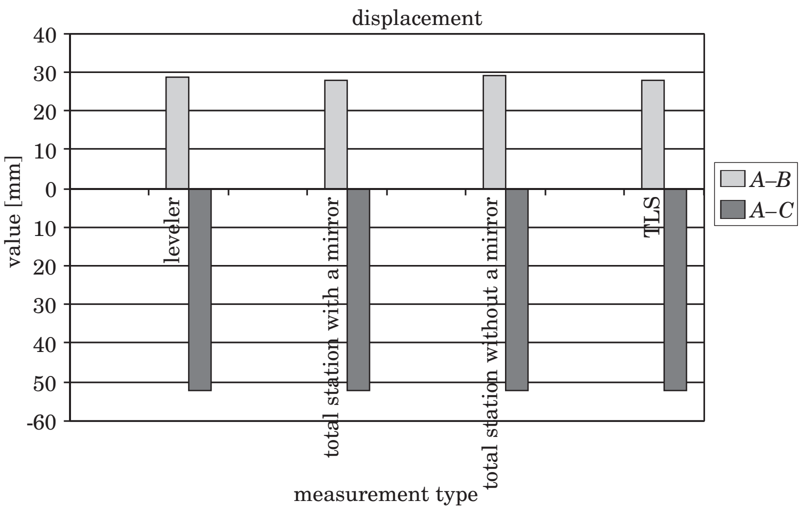

Fig. 4. Graphical Interpretation of measurement results
Source: own development.

Where displacements of a engineering structures are measured it is sometimes impossible to mark the objects with HDS shields. However, it is usually possible to find some distinct points that can be easily identified in the following measurement epochs. The tester that was applied in the research project also had such points. I chose one point, namely a clamp, which is pointed with the arrow in Figure 5. This characteristic point was scanned to determine its coordinates, which was the basis for computation of displacements. The results were compared with the precise leveling, and are presented in Table 3 and in Figure 6.

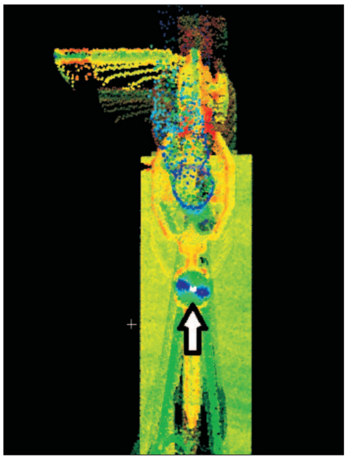

Fig. 5. Tester with measured point indicated (arrow)
Source: own development.

Table 3

Displacement Values

Displacement	Precise leveler [mm]	Direct measurement [mm]
A-B	28.6	29.0
A-C	-52.0	-51.0

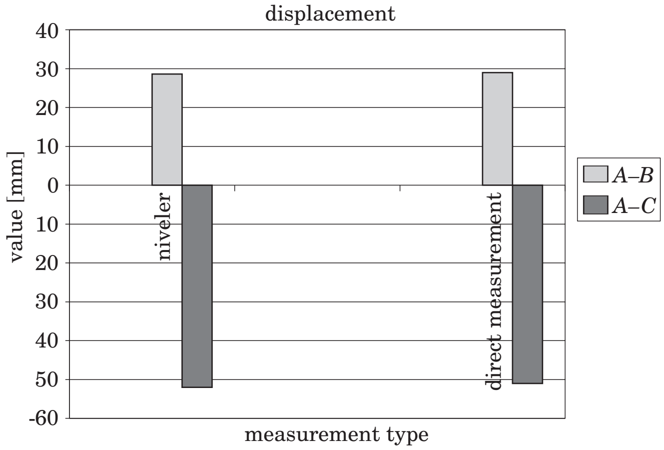

Fig. 6. Graphical Interpretation of the measurement results
Source: own development.

Conclusions

The results of the research project allow to formulate some general conclusions. The values of the displacements obtained by applying different methods are almost the same. The differences of 1 mm are within the accuracy of the measurements. Such good convergence results from rather small, few meters, distance between the measured object and the instruments. It is worth noting that a change of HDS shield for certain distinct point does not reduce the measurement accuracy. Thus, it is not necessary to mark object that are hard in access. However, one should choose only these points that are uniquely identifiable. In conclusion, the results of the laser scanning are very similar to the results of the trigonometric method (electronic tachimeter) as for the accuracy. Thus, the laser scanner can be an alternative to more conventional methods. The advantage of the laser scanning is large number of observations, which allows us not only to study displacements pointwise but also to do some spatial analyses (e.g., deformation)

Translated by ROBERT DUCHNOWSKI

Accepted for print 28.03.2011

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