TECHNICAL TRANSACTIONS 1/2018
ENVIRONMENTAL ENGINERING
DOI: 10.4467/2353737XCT.18.012.7963
SUBMISSION OF THE FINAL VERSION: 4/1/2018

Maria Elżbieta Kowalska (m.kowalska@gik.pw.edu.pl)
Janina Zaczek-Peplinska (j.zaczek-peplinska@gik.pw.edu.pl)
Faculty of Geodesy and Cartography, Warsaw University of Technology

Examples of measuring marks used in geo-reference and the connection between classic geodetic measurements and terrestrial laser scanning

Przegląd znaków pomiarowych wykorzystywanych do georeferencji i powiązania klasycznych pomiarów geodezyjnych z naziemnym skaningiem laserowym

Abstract

In the era of the development of modern measurement technologies, their interconnectedness is of high importance. This paper presents a review of the most popular, currently utilised measuring marks in tachymetric measurements and in object laser scanning. This paper presents the authors' own solutions that facilitate the linkage of data acquired through terrestrial laser scanning with tachymetric measurements. The proposed marks used to perform orientation on the scanned surfaces were successfully tested in the field with the use of laser scanners manufactured by the Z+F, Leica and Riegl companies. The document describes the consecutive steps that eliminate individual problems that arise during both tachymetric measurements and laser scanning. As a result of the work, a new kinds of marks were created allowing tachymetric measurements and laser scanning at the level of accuracy that is required for basic engineering measurements. This paper also presents a discussion on how to prepare the marks yourselves and the marks durability on the surface of the surveyed object.

Keywords: terrestrial laser scanning, marks, targets, engineering surveys

Streszczenie

W dobie dynamicznego rozwoju nowoczesnych technologii pomiarowych bardzo istotne jest ich wzajemne powiązanie. W artykule przedstawiono przegląd najpopularniejszych, aktualnie stosowanych znaków w klasycznych pomiarach tachimetrycznych oraz znaków stosowanych przy skanowaniu obiektów skanerami laserowymi. Zaprezentowano autorskie rozwiązania ułatwiające powiązanie danych z naziemnego skaningu laserowego z pomiarami tachimetrycznymi. Zaproponowane znaki do lokalizacji na skanowanych powierzchniach zostały z sukcesem przetestowane w warunkach terenowych przy wykorzystaniu skanerów laserowych firm Z+F, Leica i Riegl. Opisano kolejne etapy postępowania eliminujące poszczególne problemy zarówno w pomiarach tachimetrycznych, jak i w przypadku skanowania laserowego. W wyniku opisanych prac powstał nowy rodzaj znaku umożliwiający pomiar tachimetryczny, jak również skanowanie laserowe z odpowiednią dokładnością wymaganą dla podstawowych pomiarów inżynierskich. W pracy przedstawiono również rozważania na temat wykonania samych znaków i ich trwałości na mierzonym obiekcie.

Słowa kluczowe: naziemny skaning laserowy, znaki pomiarowe, tarcze pomiarowe, pomiary inżynierskie

1. Introduction

Terrestrial Laser scanning is a measurement technology which is commonly used in geodetic work. In terrestrial laser scanning, the result of the measurement is presented in the form of a point cloud (X, Y, Z) along with the information on the reflected beam's intensity value. The registered point cloud contains complete information on the shape and size of the object [7] – this is quasi-continuous information not limited to individual, flagged points. Additionally, registration of the intensity value of the beam reflected from the object's surface allows the analysis of its spectral properties.

The data obtained through terrestrial laser scanning is complemented with additional information, making it easier to interpret the point cloud. Currently, the majority of the scanners are integrated with a photo camera (digital images) which, in turn, allows the 'covering' of the created models with textures and presenting it in colours similar to those in the real world.

Based on the spatial data obtained through terrestrial laser scanning, it is possible to conduct various types of surveying studies, such as: deformation and shift analysis [1, 9]; architectural inventories [4, 5, 8]; spatial and numerical models of objects and terrain [2, 10]. There have been attempts to use terrestrial laser scanning in order to create maps for design purposes and permanent monitoring of engineering works. Such dynamic development of this technology is chiefly due to its huge capabilities.

More than once, terrestrial laser scanning has been combined with classic geodetic measurements – tacheometry or levelling. The combination of these technologies requires the application of special solutions, including properly designed measurement marks. The authors of this paper focus on reviewing the issues connected with marks that make it possible to combine terrestrial laser scanning with tacheometry.

2. Marks dedicated to tacheometric measurements

In order to refer the point cloud obtained through terrestrial laser scanning with the external spatial coordinate system, it is necessary to register points with known coordinates on the scans. In classic angular and linear measurements, points of measurement are indicated using a prismatic mirror or a measurement foil (reflective – mounted on the surveyed surface).

Reflective material used in the production of foil which is good for distance measurement causes problems in the precise identification of measured point placement on the scans, both in the plane of the scanned surfaces and in a perpendicular direction – this can be observed on Illustration 1 in the form of a blurred point cloud.

Similar problems occur when analysing point placement flagged using prisms (Fig. 2).

The problem can be solved by adjusting the marks used in terrestrial laser scanning in such a way that they would serve their purpose with regard to angular and linear measurements. This mainly concerns the aspect of the precise identification of the centre of the mark (target).

Fig. 1. Blurrification of the point cloud presenting control points made from reflective foil [9]

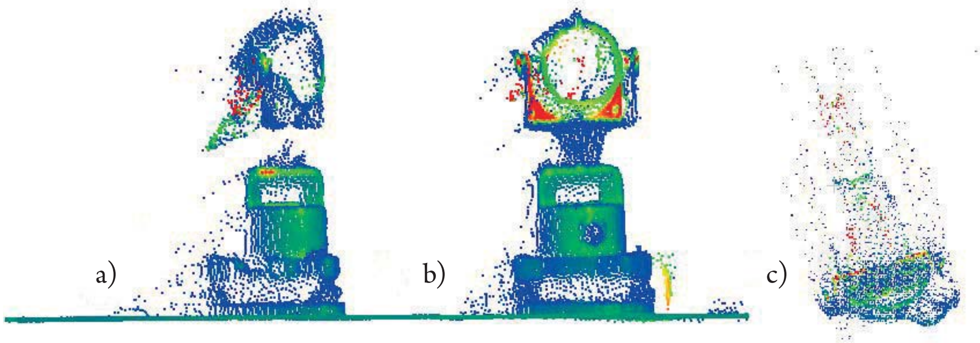


Fig. 2. View of a scanned precision reflector: a) a mirror set at an angle to the scanner b) mirror positioned in front of the scanner c) the view from the top scanned mirror

3. Measurement marks used in terrestrial laser scanning

Terrestrial laser scanning, like every measurement technology, possesses its own special measurement marks determined by the manufacturers in the form of targets, spheres or code disks. Depending on the manufacturer, they differ in colour, texture and geometry. When using the registered reflected beam's intensity value (Intensity), high-contrast fields on disks allow the precise identification of their location (Fig. 3) [6]. Disk manufacturers define the possible precision of identification if their placement even at the range of 0.2 mm.

Even though the precision with which the centre of a disk is identified is unquestionable, the use of these marks in tacheometric measurements proves problematic. One has to remember the difference between the nominal and expected precision of point placement for both measurement technologies – laser scanning 0.5–5.0 cm (depending on the precision of distance and angle measurement, accuracy of angular offset of the measuring beam and geometric properties of the scene); tacheometry – 0.2–0.5 cm.

The basic problem with using those marks in tacheometry lies in aiming, unambiguous on the scan, the dark-grey and white target blends with the crosshair in tacheometer causing the operator difficulty in judging the positioning. It is also difficult to interpret the middle of the board as in large magnification of telescope instead of clear-cut interesting lines, four adjacent monochromatic planes can be observed. The authors of this article, based on their measurement experience, suggested an improvement to those measuring marks by adding

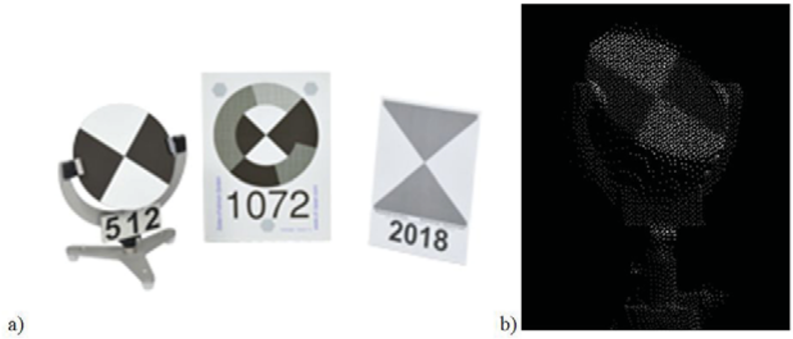


Fig. 3. Professional signal disks dedicated to terrestrial laser scanning a) mark appearance (source: http://www.zf-laser.com) b) example of visualisation of a disk using the registered reflected beam's intensity value (source: authors' archive)

a high-contrast crosshair to the target (Fig. 4). This solution facilitates and improves the aim with the telescope's crosshair and, at the same time, it avoids causing a deterioration in the quality of the mark when it is used for terrestrial laser scanning. Illustration 4 presents example targets with an integrated high-contrast crosshair.

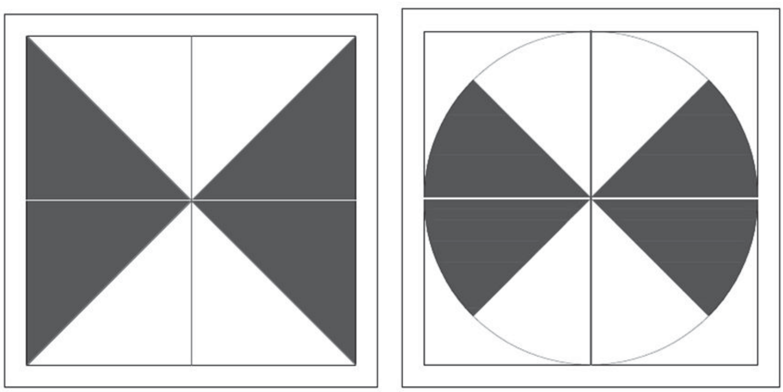


Fig. 4. Example targets with integrated contrast crosshair (source: authors archive)

The use of the above marks in angular and linear measurements requires less accurate, reflectorless measurement. In order to make use of the high accuracy of the measurement when using measurement foil, a suggestion was made to supplement terrestrial laser scanning marks with a small reflective foil. A small-sized circular ($r = 12.5$ mm) or square field ($d = 30$ mm) was designed in the middle of the mark and reflective foil was attached to it (Fig. 5, 7). This solution results in an increase in the accuracy of distance measurement and, at the same time, it makes it possible to combine it with terrestrial laser scanning. Even though the reflective foil would cause measurement noise to appear on the scan, the uncovered parts of the target would make it possible to determine its centre in the point cloud using geometric means. Due to the possibility of obtaining precise distance measurement to the mark with the attached foil and, at the same time, accurate angular and linear measurements, this mark was named the 'dual-function' mark.

Figures 6 and 7 present the proposed marks as seen through the telescope.

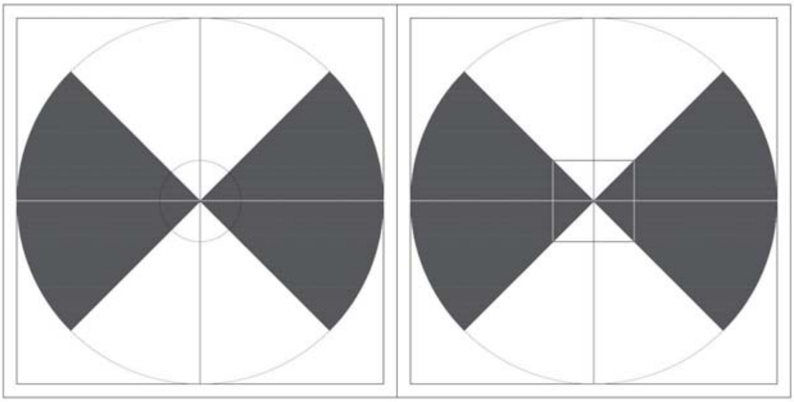


Fig. 5. Design of the terrestrial laser scanning mark with a designated field for the reflective foil

a) b)

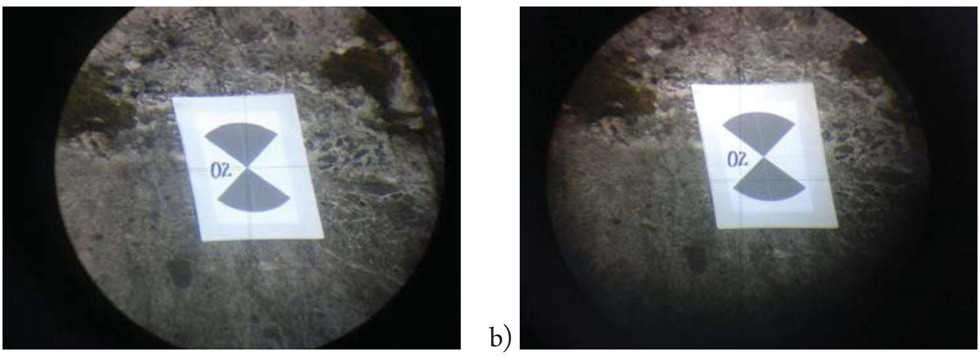


Fig. 6. View of the measurement mark in the telescope of the instrument (magnification: 30, distance: 13 m) a) crosshair properly aimed at the measurement point, b) no aimed (source: authors' archive)

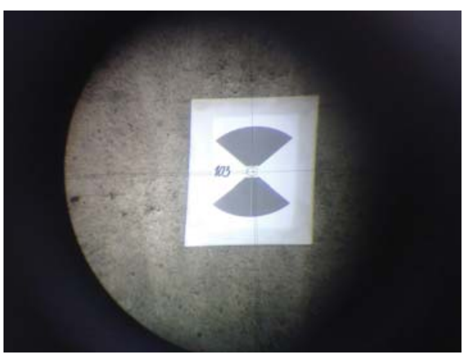
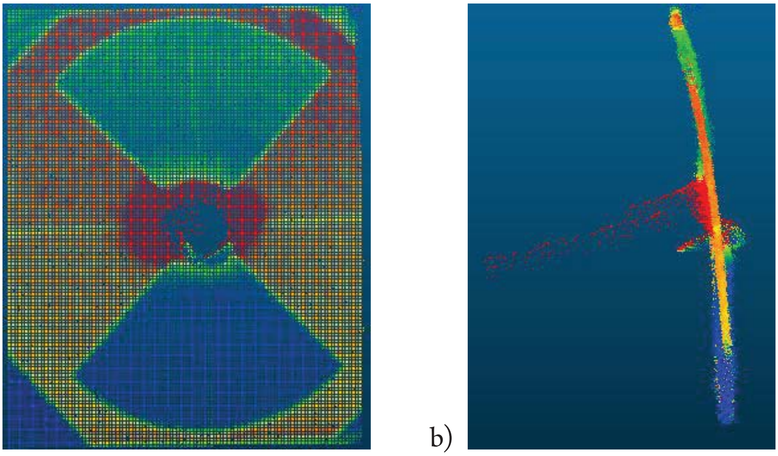


Fig. 7. Examples of aim using the mark supplemented with reflective foil (magnification: 30, distance: 13 m)

Fig. 8 presents a scan fragment of a 'dual-function' target. A blurring of the point cloud can be clearly observed where the reflective foil was attached. Also, incomplete registration of points in the centre of the foil is visible. Similar effects were obtained for targets of different sizes and different angles of the scanned surface (different angles of incidence) (Fig. 9).



a) b)

Fig. 8. View of a scanned 'dual-function' target: a) from the front and b) from the side (scans in the intensity colour range)

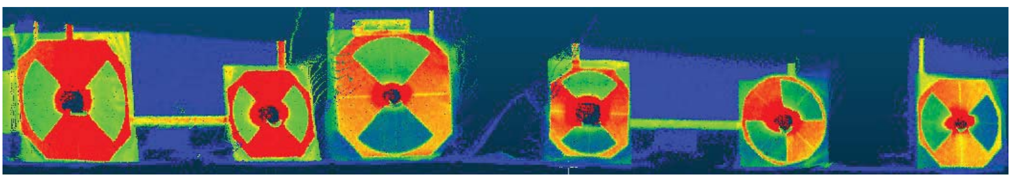
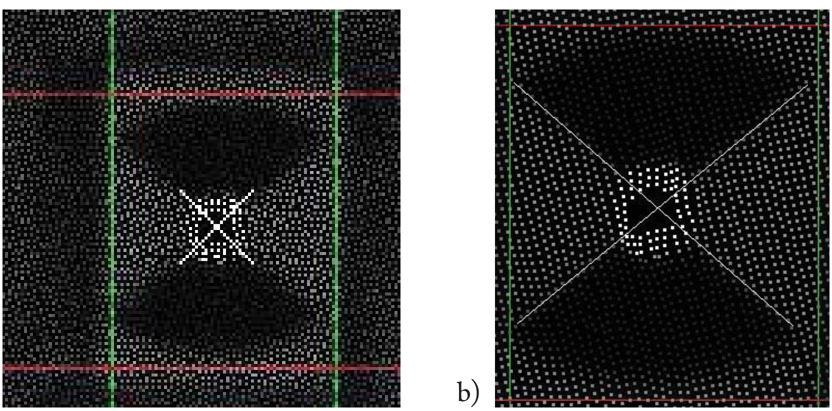


Fig. 9. An example of scans of 'dual-function' marks in different sizes and different placement. Scans in the intensity colour range



a) b)

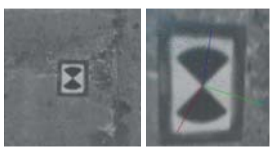
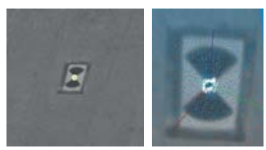
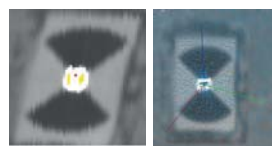
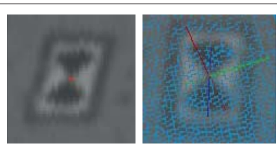
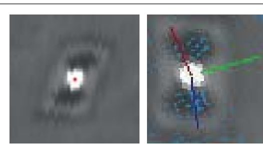
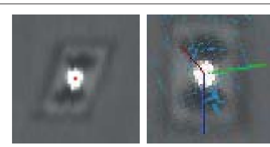
Fig. 10. Example of how the centre of a dual-function mark is identified on high-resolution scans a) using indicator of ASCAN software, b) by identifying the point of intersection of two drawn lines

As can be observed on Figures 8, 9 and 10, adding a crosshair and a small reflective foil to the marks for terrestrial laser scanning does not influence the ability to identify the disk's centre on the scan using geometric means. However, it should be emphasised that analogous to the signals dedicated to scanning, the appropriate resolution and distance should be used – the same as for signals without the added cross and reflective foil. Noise caused by the reflective measurement foil does not significantly decrease the quality of the mark. As can be observed on Table 1, the quality of marking target centres decreased by a few percent. The table below shows the results of the target centre design with cross strokes and reflective film using Z + F LaserControl software algorithms. For the purposes of the experiment, one sign with cross marks (A) was scanned from two distances (22 m and 58 m) and two signs with reflective film (B, C) were also scanned from the same two distances.

The pitch is the distance between two scan pixels. The calculation is based on the scan resolution and the distance from the scanner to the target.

The quality is due to having five different measured values. These values are standardised and calculated to be given back between 0 and 100 %. These values are: the distance to the target, the angle to the target, the fitting result, the target contrast, and the resolution.

Table 1. Summary of the quality of the centre point of the target scan

			
Sign	A	B	C
Distance	22.00 m	22.00 m	22.00 m
Quality	96%	91%	93%
Pitch	3.34 mm	3.54 mm	3.43 mm
			
Sign	A	B	C
Distance	58.00 m	58.00 m	58.00 m
Quality	93%	93%	90%
Pitch	8.92 mm	9.08 mm	9.24 mm

4. Target multiplication problem

During measurement work, marks in the form of targets for terrestrial laser scanning were prepared multiple times. The use of such marks is essential when combining scans registered on different spots (ex. during inventory). This requires the use of a large number of disks – at least 4 disks in order to combine two scans. For reasons of economy, paper copies of the disks are most often used; copies are made by printing or photocopying. When making disks on one's own, it is essential to pay attention to their colour. The use of black and white targets causes the appearance of distortions in the area of the black fields (Fig. 11). A much better visualisation is obtained when using dark grey and white boards.

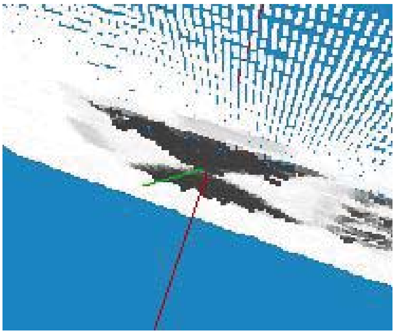
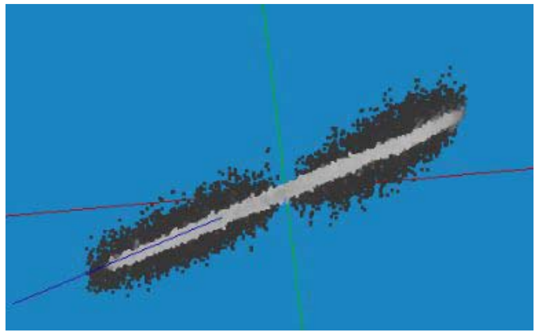
a)  b) 

Fig. 11. View of a scan when a black and white board was used; distortions of visualisation in the black field areas are clearly visible: a) view of the point cloud, b) projection of a point cloud fragment on a horizontal plane

During the experiments, it was observed that the type of print is very important. Depending on whether it is ink-jet or laser printing, the marks visualise differently. Most probably, the mineral content present in some of the inks causes the white fields to be invisible on the scans (black fields have the same spectral values as the white fields). The same disks printed on a laser device had good visualisation on the scans. Fig. 12 presents the view of the same target printed on two different printers registered in the intensity value colour range.

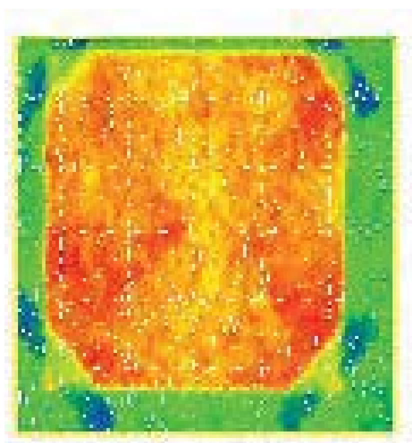
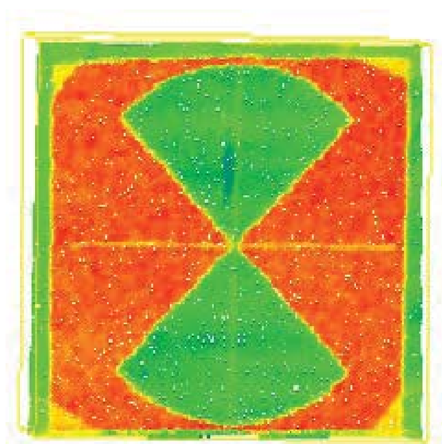
a)  b) 

Fig. 12. View of a black and white target a) ink-jet print, b) laser print

5. Target protection

As mentioned in the introduction, terrestrial laser scanning is becoming more and more commonly used in various types of monitoring. Performing periodic measurements requires leaving the marks on the object for prolonged periods of time. Atmospheric conditions – changes in temperature, humidity, high insolation – cause the paper disks which are commonly used in terrestrial laser scanning to quickly deteriorate. The authors suggested using foil laminate in order to protect the marks. Due to the fact that too much reflectivity of the scanned surface causes shortages in data registration or noise in the point cloud, 75 μm-thick matte foil was chosen. A great advantage of a matte surface lies in the fact that when used outdoors, it does not cause sunrays to be reflected from its surface.

A laminated paper mark was tested in the field. The specially-prepared targets were attached to the downstream wall of the water dam in Rożnów, using concrete adhesive (Figs 13, 14). The changing atmospheric conditions, especially the high humidity present on the dam, served as an ideal environment for the experiment. The marks were mounted in August 2013. During control measurements in October 2015, 5 out of 25 mounted marks, that is 20% of all the mounted marks, remained intact on the wall. Most probably, the destruction of the remaining marks might have been caused by the fact that they fell off, as concrete adhesive which was not strong enough was used and the surface under the marks was not cleaned properly (a height of 6 m – this required the use of an aluminium ladder fixed to the wall, which was not conducive to thorough cleaning). The marks that remained after over two years had an excessive level of soiling; however, their structure was undamaged and they were not deformed or discoloured (Fig. 15). Some soiling could be removed by wiping the mark with a cloth.

Fig. 13. Marks mounted in August 2013, view of the whole test field

Fig. 14. Close-up on one of the marks mounted in the test field, August 2013

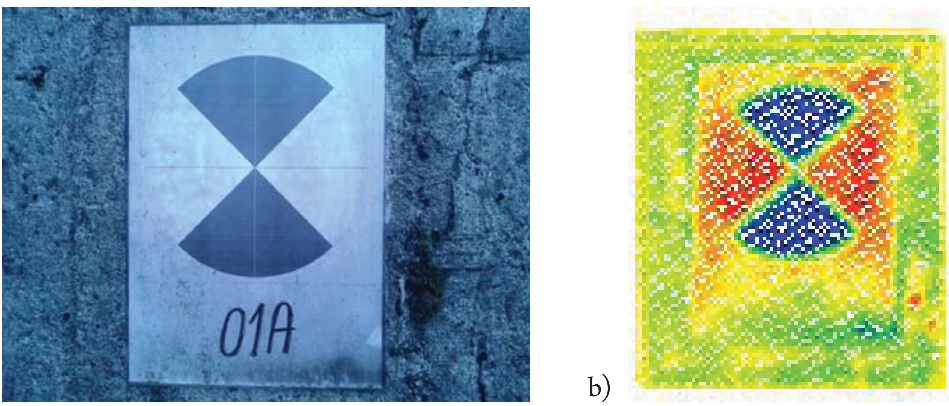
a) b)


Fig. 15. Close-up on the mark that survived in the test field for over two years, October 2015
a) digital picture, b) point cloud fragment

6. Summary

In the existing works, a major emphasis was put on the decrease of the scan's reciprocal orientation connected to decreases in the ability to identify the centre of the mark as the scan's resolution decreases [3]. The decrease in the ability to orientate the scans is visible on Illustration 16, presenting images of marks created using various scanning modes.

The tests presented in the paper show that focusing on the problem of variable resolution does not cover all the needs of surveying engineering. The described results of the tests to utilise unaltered tachymetric marks in scanning as well target marks and other marks dedicated to scanning in tachymetry, unambiguously show that universal, alternate use of the marks is practically impossible or at least does not fulfil the high accuracy requirements present in surveying engineering.

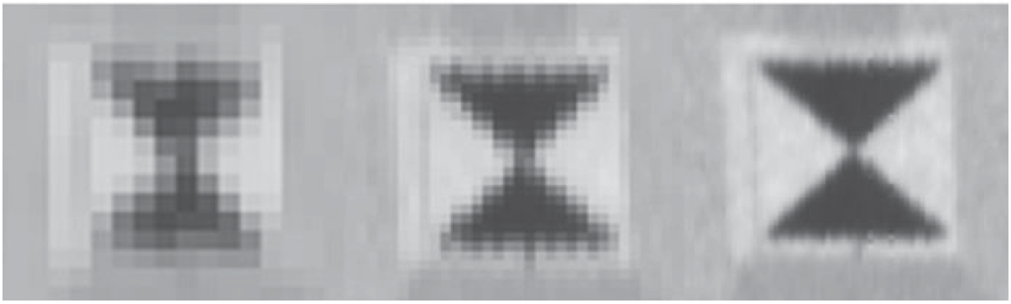


Fig. 16. Target mark images using scanning modes: high (6 mm / 10 m), super high (3.2 mm / 10 m), ultra-high (1.6 mm / 10 m), the images scaled to one size (Z+F Imager 5006 scanner) [3]

The consecutive stages of the preparatory marking process eliminating individual problems that arise both during tachymetric measurements and laser scanning presented in the paper led the authors to the creation of a new kind of mark – a high-contrast target in the form of a circle with a crosshair (Fig. 5). This mark allows accurate direction measurement and is well presented on inventory scans of objects.

The proposed method of foliating the marks with a layer of thin, matte foil appears to be a good protection measure in cases where they remain on the object for an extended period of time. Marks described in the text were fixed to an inclined concrete surface and, without any additional protective measures, remained on the object in good condition for a period of two years. After that time, they were still usable and no detriment in the ability to identify the direction or the centre of the mark on a scan was observed.

Reference

[1] Abellan A., Jaboyedoff M., Oppikofer T., Vilaplana J.M., *Detection of millimetric deformation using a terrestrial laser scanner: Experiment and application to a rockfall event,* Nat Hazards Earth Syst Sci., 03/17, 9(2), 2009, 365–372.

[2] Brasington J., Vericat D., Rychkov I., *Modeling river bed morphology, roughness, and surface sedimentology using high resolution terrestrial laser scanning,* Water Resources Research, 2012, 48(11).

[3] Markiewicz J., Kowalczyk M., Podlasiak P., Krzysztof B., Zawieska D., Bujakiewicz A., Andrzejewska E., *Analiza wpływu rozdzielczości danych źródłowych na jakość produktów fotogrametrycznych obiektu architektury,* [In:] *Measurement technologies in surveying. Geodezyjne technologie pomiarowe,* ed. Kurczyński Zdzisław, 2013, 69–84.

[4] Pu S., Vosselman G., *Knowledge based reconstruction of building models from terrestrial laser scanning data,* ISPRS Journal of Photogrammetry and Remote Sensing, 64(6), 2009, 575–584.

[5] Riveiro B., Morer P., Arias P., De Arteaga I., *Terrestrial laser scanning and limit analysis of masonry arch bridges,* Construction and building materials, 25(4), 2011, 1726–1735.

[6] Štroner M., Smítka V., Třasák P., *Evaluation of Accuracy of Control Points´ position using a Laser Scanning System Leica HDS3000*, Reports on Geodesy, Warsaw University of Technology, Warszawa 2011, Vol. 90, No. 90.
[7] Vosselman G.V., Maas, H. G., *Airborne and terrestrial laser scanning*, Whitles Publishing 2010.
[8] Zaczek-Peplinska J., Pasik M., Adamek A., Adamek A., Kołakowska M., Łapiński S., *Monitoring technical conditions of engineering structures using the terrestrial laser scanning technology*, Reports on Geodesy and Geoinformatics, 95(1), 2013, 1–10.
[9] Zaczek-Peplinska J., Popielski P., *Utilisation of terrestrial laser scanning for verification of geometry of numerical models of hydrotechnical structures using the example of a section of the concrete Besko Dam*, Czasopismo Techniczne, 10/2013, 110.
[10] Zaczek-Peplinska J., Adamek A., Kowalska M., Pasik M., Łapiński S., Adamek A., Baran M., *Inwentaryzacja stanu i monitorowanie deformacji ścian szczelinowych z wykorzystaniem technologii naziemnego skanowania laserowego*, [In:] *Teoretyczne podstawy budownictwa. Tom VI. Geodezyjne systemy pomiarowe*, eds. J. Kulesza, I. Wyczałek, Oficyna Wydawnicza Politechniki Warszawskiej, Warszawa 2014, 51–58.