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# Comparison of 3D Laser Scanning and Classical Survey Data Deformation Analysis of Industrial Facilities in Oil Refinery

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## Abstract

Terrestrial laser scanning is an advanced measuring technology, which can record a huge number of data with high accuracy. Because of its characteristics, nowadays it has established itself in many fields, like forensics, architecture, civil engineering, archaeology, etc., but for some uses classical geodetic methods are still unsurpassed or at least a standard for comparison with modern methods like 3D laser scanning.

In this paper, a specific example of 3d deformation analysis on industrial facility in the Oil refinery Sisak is described. Industrial survey, and deformation analysis is a very demanding part of geodesy, so it requires high density and high data accuracy. The water pump in oil refinery Sisak was measured with a terrestrial laser scanner in order to define geometry, to create a model and to find out if there are deformations present on the pump which cause small vibrations that damage the facility during long runs.

For this purpose, we will try to show that using high precision modern laser scanner and two different independent software approaches, one commercial and the other, own program written in Matlab, can get solutions of deformation analysis with accuracy comparable to conventional surveying methods. It was shown that the use of laser technology is highly effective. It can very precisely define and analyse the object with incomparably better visualization of corresponding output data than the use of classic geodesic methods with the same order of accuracy.

**Key words:** terrestrial laser scanning, industrial survey, terrestrial laser scanner, geometry analyse, visualization of the data

## 1 INTRODUCTION

Deformations of industrial facilities occur often and cause significant problems for proper functioning of the facilities. Some deformations are too small to be identifiable by sight, but high precision geodetic methods like high precision levelling or 3D laser scanning allow detection of even the smallest of deformations (Babic et al. 2011, 2014, 2016). Thus, surveyors are indispensable in the process of identifying and dealing with deformations to mechanical engineers. Laser scanning, unlike other geodetic methods (total station, levelling, GPS), provide a means for a high precision yet fast survey of affected surfaces and objects.

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Poster Session

The research described in this paper was motivated by the need to verify the efficiency and precision of this method in relation to conventional surveying methods.

The Faculty of Geodesy, University of Zagreb is often engaged in solving special engineering problems on industrial facilities like the Sisak Oil Refinery. The Sisak Oil Refinery is a continental refinery, located some 50 km south of Zagreb. It is positioned on an intersection of road, rail and watercourse transit lines, close to domestic oil fields. It is part of Sisak's industrial zone covering an area of 165 ha. The project goal was determining if there are deformations on water pumps in the Refinery as there were reported irregularities attributed to vibrations caused by shifts of connecting planes that are supposed to be parallel.

Mechanical engineers expressed suspicions regarding the cylinders, thinking they were no longer properly inclined, and that they are at the root of observed irregularities and vibrations. Hence, the geometry and possible deformations had to be determined. 3D laser scanner was used for survey to allow creation of a model of the cylinders, and determining whether their connecting planes were perfectly horizontal and parallel to each other. As an independent control, high precision levelling survey was conducted to determine flatness and if they are parallel. Another control that was decided upon was that of the software packages that the scanner manufacturers provide. Hence, an algorithm was designed and implemented using Matlab (URL 3) program package.

## 2 FIELD SURVEY

Field survey in the Refinery's water pump section was conducted on 15th of March 2013. Faro Focus 3D laser scanner, precise levelling stations Leica DNA 03 and SOKKIA SDL 30 and a Trimble S6 total station were used for the survey.

Surveys were performed by scanning the pump from four sides, about 1.5 m away from the reference planes for which spheres were positioned around the pump for positioning and point cloud matching. The total station was used to determine the coordinates of the spheres for establishing a reference frame for future control surveys. An additional control of the scanning survey was a survey using precise levelling stations Leica DNA 03 and SOKKIA SDL 30 for determining the flatness and if there is inclination between the plains or if they are parallel.

Data processing was done using Faro SCENE (URL1) and Trimble RealWorks (URL 2) software solutions. Georeferencing of the obtained data and point cloud matching was done using Faro SCENE: This resulted in a singular point cloud of the water pump containing 32.288.328 points. For the following data processing and analysis, Trimble RealWorks was used.



Fig 1. Raw data loaded into Faro SCENE

As the water pump in question consists of three cylinders connecting in three separate planes, it was necessary to isolate those planes and determine their inclination to a horizontal plane which will then answer the question whether there are any deformations. For this purpose, a segmentation tool was used to extract parts of the point cloud representing or in close vicinity of each connecting plane. The result is shown in Image 2. where smaller pointclouds representing said planes can be seen.

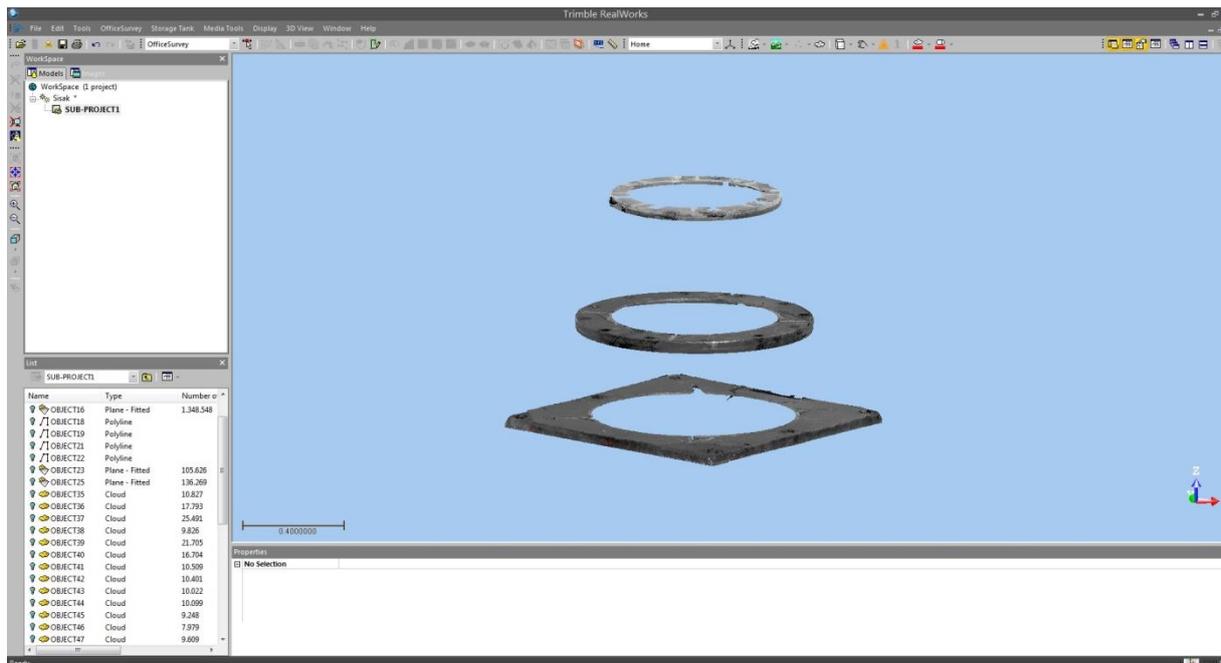


Fig 2. Extracted point cloud data using segmentation tool

Considering that the density of the acquired points was too great it was necessary to make it smaller to enable calculation and plane fitting on a balanced point group for a finite element analysis. Hence, a sampling tool was used to reduce the extracted point cloud with a 1 mm

spatial sampling distance parameter. This produced the required point sets for the intended analysis. Image 3. shows the planes fitted to best match each individual point set. Normal vectors were then taken from the planes to determine their spatial position and orientation, and to determine if they are horizontal as well as parallel to each other.

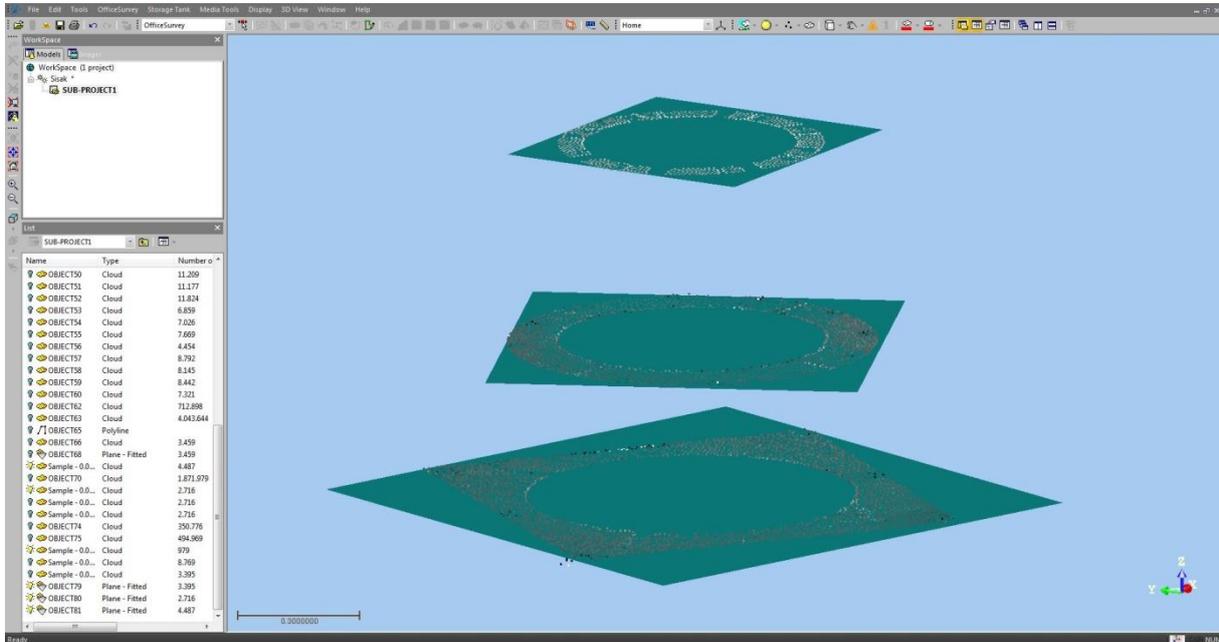


Fig 3. Planes fitted in the extracted pointclouds

During point extraction, i.e. point cloud segmentation, a significant noise level was observed. This was primarily the result of survey conditions but on a certain level also the specifications of the instrument used. Still, considering that plain fitting is done using least squares adjustment, and that the noise is of constant and equal intensity, it was deduced that the possibility of significant divergence of the resulting plane fitting from an actual value was small to nonexistent. This assumption was also confirmed with the correlation of the results with the values obtained from precise levelling survey used as an independent survey quality control. The resulting analysis shows that there are discrepancies in results of each plane fitting, that they are not completely parallel and horizontal, but also that those discrepancies are very small as can be seen in Table 1. that shows the resulting normal vectors.

Table 1 Calculated normal vectors of each plane (from lowest to highest)

	XYZ values of the normal vectors		
Bottom plane	0.0015 m	0.0026 m	1.0000 m
Middle plane	-0.0013 m	0.0006 m	1.0000 m
Top plane	0.0002 m	-0.0003 m	1.0000 m

### 3 DETERMINING AND VISUALISING DEFORMATIONS

Flatness of the planes was the next analysis that had to be made. Thus, a deviation of the planes from their geometrically ideal counterparts created in the previous step was calculated. For extra control, the point sets derived previously were subjected to noise filtering using an algorithm designed to take into consideration the points surroundings, i.e. the “behaviour” of the neighbouring points. Colour coded analytical representations were then created for each plane graphically depicting deviations of each surface from its corresponding ideal counterpart (Image 4.). A simple visual inspection shows that the majority of deviations is in the range of  $\pm 2$  mm and that the extreme values (over  $\pm 3$  mm) can be found in marginal areas where surface data instead becomes data of other elements like bolts and other construction elements or simply represents a no data due to obstruction or surface edge.

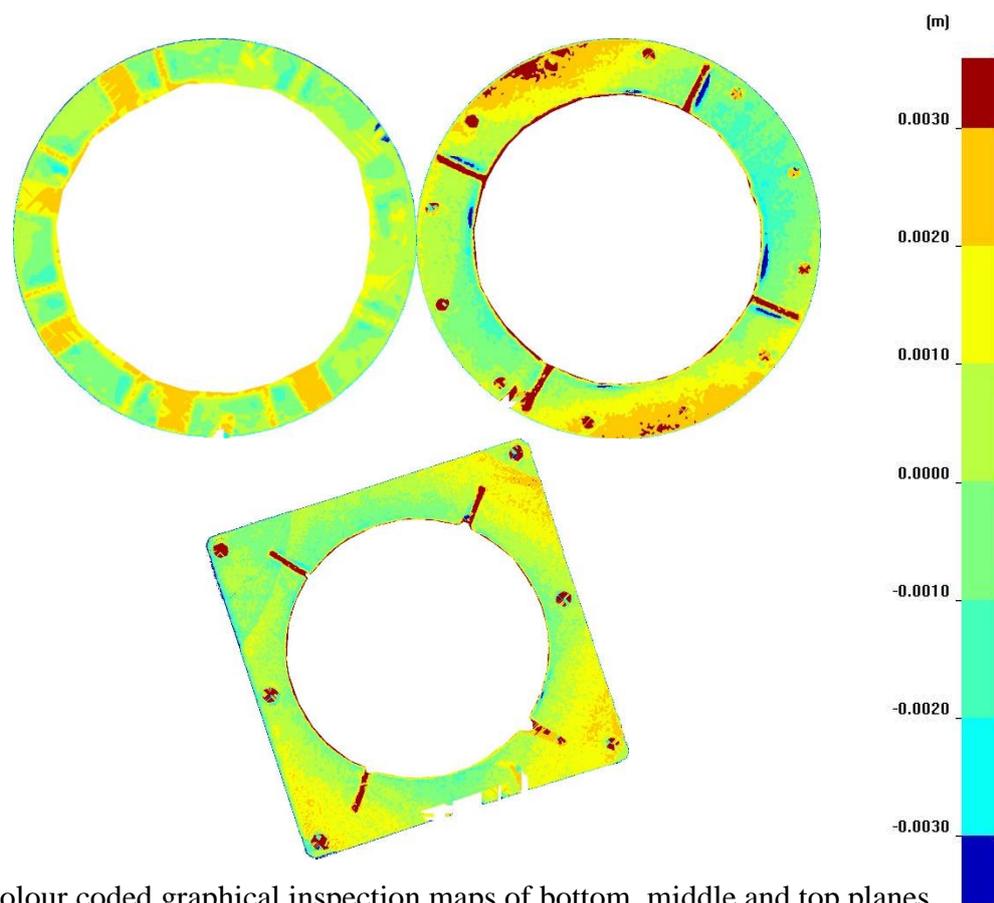


Fig 4 Colour coded graphical inspection maps of bottom, middle and top planes

After the analysis and controls made using Trimble RealWorks software package, testing and analysis of results provided by that software was also made to determine its reliability and accuracy. For this purpose, Matlab software package was used.

#### 3.1 ANALYSIS OF PLANE FITTING RELIABILITY AND ACCURACY USING MATLAB

To further control of the algorithm used by Trimble RealWorks for defining the plane using point clouds and determining its reliability and accuracy, the point sets used for plane fitting had to be used an analysed in an independent algorithm using Matlab as a platform for

calculation. For this the algorithm was programmed into Matlab and was set to use points from an xls file that were the same points used in Trimble Realworks for plane fitting. The xls file was created by exporting the mentioned point sets to ensure there is no discrepancy in input data. The programmed algorithm does the calculation and stores the results in a new xls file where it writes the plane equation and the accompanying normal vector. The normal vector derived from the Matlab calculation is then compared to the corresponding one obtained from Trimble RealWorks to determine if there are any significant discrepancies. The algorithm programmed in Matlab is a functional model of indirect measurements using a regular equalization of indirect measurements. Initially the number of measurements, unknowns and redundant measurement were determined. After which the indirect measurement function was defined:

$$t_i + v_i = y_i \bar{A} + x_i \bar{B} + \bar{C}$$

While the error correction equation is:

$$v_i = y_i A + x_i B + C + (y_i A_0 + x_i B_0 + C_0 - t_i) \text{ , where } i=1, 2, \dots, n$$

As the model in question is a linear model it is not necessary to have the initial values of the unknowns close to the actual value, so zero coefficient values were used. Then a coefficient matrix of correction equation was formed as well as a reduction shift vector. The calculation itself was performed using Gaussian least-squares adjustment. After calculation, standard deviation of unknowns and the measured values was determined. All the above was programmed into Matlab.

The next tables show the comparison of normal vector values obtained from doing calculations in Matlab using a known algorithm and programming code (Table 2.) and the one from Trimble Realworks (Table 3) using the same point sets.

Table 2 Normal vectors calculated in Matlab

	Normal vectors calculated in Matlab					
<b>Bottom plane</b>	0,0001802	m	-0,0003014	m	0,9999999	m
<b>Middle plane</b>	-0,0012629	m	0,0006170	m	0,9999990	m
<b>Top plane</b>	0,0014603	m	0,0026044	m	0,9999955	m

Table 3 Normal vectors derived from Trimble RealWorks.

	Normal vectors derived from Trimble RealWorks					
<b>Bottom plane</b>	0,0001803	m	-0,0003014	m	0,9999999	m
<b>Middle plane</b>	-0,0012630	m	0,0006171	m	0,9999990	m
<b>Top plane</b>	0,0014603	m	0,0026045	m	0,9999955	m

It is clearly visible from the results shown in tables 2 and 3 that the values have great correspondence. Thus, a conclusion can be made that the Trimble RealWorks' algorithm is using is giving off good results, and the differences found too small to be of significance. It is important to note that the calculation was performed on a set several thousand points large, giving the result additional gravity. Graphical interpretations of planes calculated in Matlab are presented below.

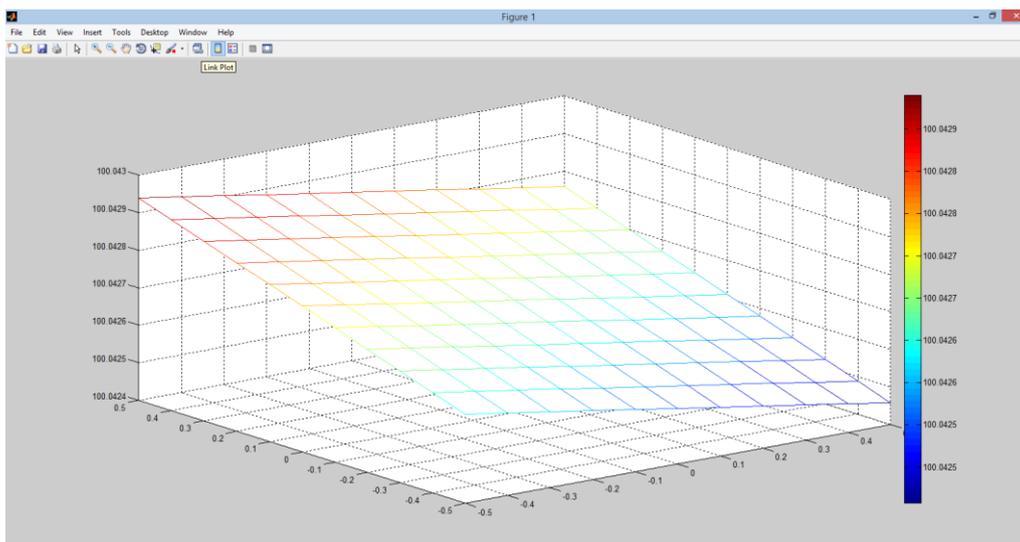


Fig 5 Bottom plane as calculated in Matlab

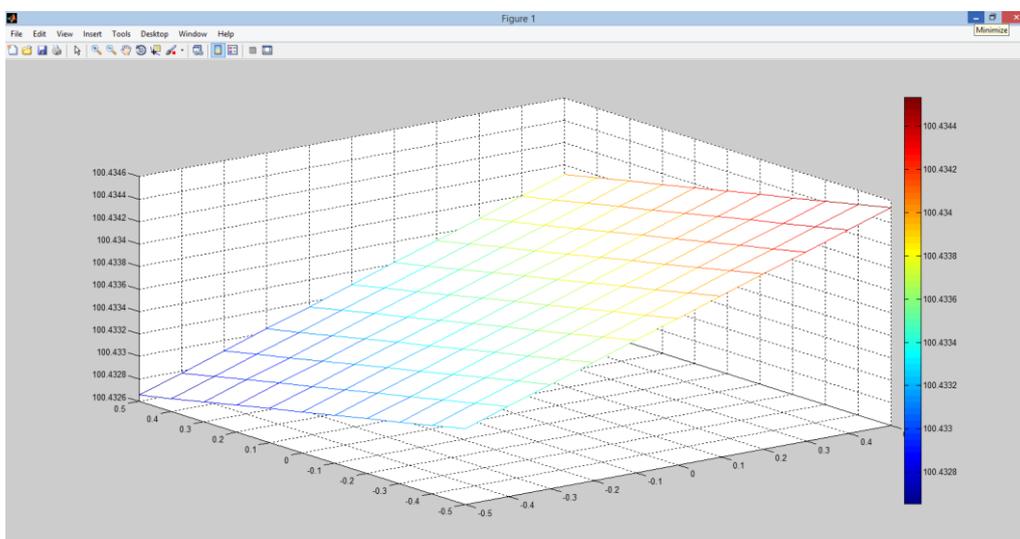


Fig 6 Middle plane as calculated in Matlab

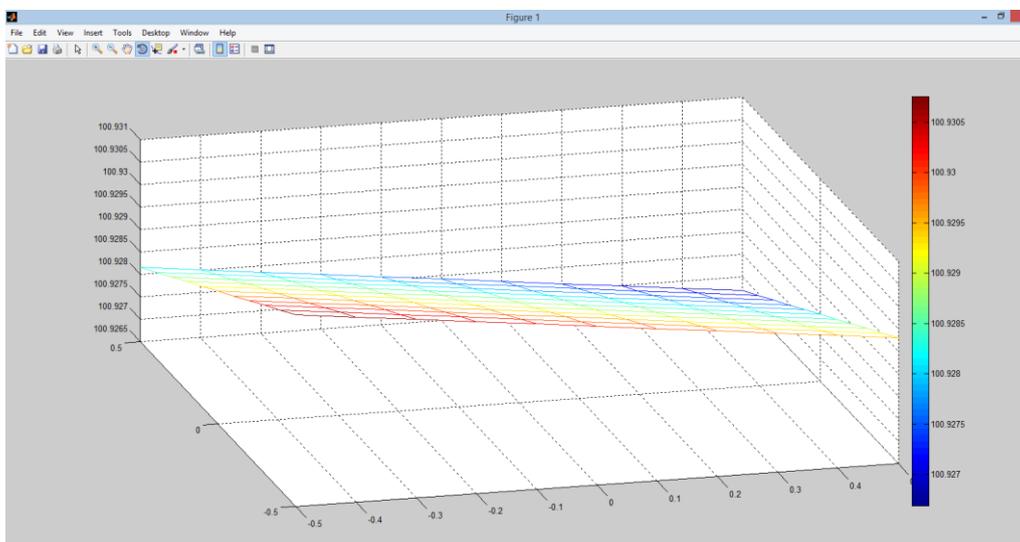


Fig 7 Top plane as calculated in Matlab

Furthermore, as there were undoubtedly gross errors among the thousands of points used for plane calculation, and Trimble RealWorks doesn't provide an algorithm or report that it identifies those values or lowers their significance, an iterative calculation was also performed using Matlab.

After the first calculation standard deviation was determined, both the standard deviation of unknowns and the standard deviation of equalized values. Using those a new weight matrix was formed based on those values using the formula:

$$P_i = \frac{s_0^2}{s_i^2}$$

Where  $s_0$  is the reference standard deviation, and  $s_i$  standard deviation of each individual value. This is a diagonal matrix of  $n \times n$  size. Weights of individual values obtained after the first calculation and calculated by the above formula are positioned diagonally. All other values are defined as zero values under the assumption the points are not correlated. This procedure created a so called "smoothing algorithm" for the points. The calculation was performed in 10 iterations for each plane and the following results were obtained.

Table 4 Calculated normal vectors in 10 iterations

	Normal vectors after 10 iterations					
Bottom plane	-0,00023158	i	0,00021135	j	-0,99999995	k
Middle plane	0,00150418	i	-0,00064205	j	-0,99999866	k
Top plane	-0,00148635	i	-0,00264305	j	-0,99999540	k

The results clearly show that the values differ very slightly to those derived without using weighted values. Differences are small enough that they can be ignored in most tasks as they are on the tenth of millimetre scale, but they certainly need to be taken into account when dealing with calculations requiring higher accuracies.

The reason 10<sup>th</sup> iteration was the limit was that the values changed very little or not at all after this iteration so it is meaningless to continue with the calculations. The value changes is presented for the middle plane in Table 4. The number of iterations can be predefined and set in the program, or a difference between two consecutive iterations can be used to define the need for further iterations. If difference value is set, the loop will stop and report the last calculated value after meeting the required condition.

Considering the project presented, it was determined that the connecting planes were indeed parallel, and that the discrepancies determined were too small to consider as deformations but rather as environmental influences. That means that the cylinders moving isn't what happened or the cause of the vibrations, but that those have a different source.

## 4 CONCLUSION

Terrestrial Laser Scanning is the technology that sparks revolution in spatial data world, including the world of geodesy. Technology allows collecting more than one high-accuracy

data in a much shorter time interval than all other geodetic methods. Although it can no longer be said that this technology is still in its “infancy”, it is still not widely spread, mostly because of the relatively great cost of 3D scanners, we can still say that it is economic in long-term. Due to the great savings on time spent on the field, and as "Time Means Money", the investment pays out relatively fast. One of the main advantages is the quantity and comprehensiveness of the spatial data collected that enable a variety of demanding, visually desirable data analysis that could not be done on classical geodetic measurements.

In this paper, we have shown that terrestrial laser scanning gives the possibility of high quality visualization and high accuracy comparable to classical precision geodetic measurements. An example of the control and verification of 3D laser measurements with a precise geodetic instrument shown in this paper confirms that.

This is a great advantage compared to other geodetic methods. "Beautiful packaging" is the bestselling product. Current geodetic engineering products are most often projected into a plane at a certain scale and legend, which for an everyday layman represents an “unnatural display with instructions for use”.

Laser 3D technology allows the product to be displayed in a natural three-dimensional form. An illustration that is much clearer and more natural because it is an integral part of everyday user environment. Humans, as living beings who see, live and think three-dimensionally, will be much easier to identify with the depiction of those in their eyes, lives, and thoughts. Overall, laser scanning technology opens many areas of application to the geodetic profession, and creates opportunities for geodesists to specialize in this technology for meeting future requirements.

The analysis of the results with the independent software package which we created in the Matlab has proved that the software that comes in the package along with the 3D laser scanner is very high quality, although the “black box” nature of commercial software does not allow us to know which algorithms were used. From the analysis of the software implemented within the work, we have seen that it meets the highest demands regarding accuracy and precision. Here it is important to note that only one program package was tested, which does not necessarily mean that they are all equally good. The task for us engineers as responsible geodetic experts is to take this fact into account when working on various software. High level of accuracy and detail, are main requirements for industrial surveys. The conclusion here is that laser scanning and related software have fully met both requirements.

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