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POINT CLOUD UNIFICATION WITH OPTIMIZATION ALGORITHM

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Abstract

Terrestrial laser scanning is a technology that enables to obtain three-dimensional data – an accurate representation of reality. During scanning not only desired objects are measured, but also a lot of additional elements. Therefore, unnecessary data is being removed, what has an impact on efficiency of point cloud processing. It can happen while single point clouds are displayed – user decides what he wants to deleted and does it manually, or by using tools provided in dedicated for point cloud processing softwares. In Leica Geosystems Cyclone – software used here in tests, user can apply tools e.g. for merging or unification of point clouds. Both of them change the separate points clouds into one points cloud, however unification can be executed with reduction – low, medium, high, highest or no reduction at all. It should be noted, that the modeled objects may have complex structure and unification with selected type of reduction can have a very big impact on the result of modeling. In such situation it is desirable to apply different types of reduction.

In this article authors propose to apply an optimization algorithm on unified point clouds. Unification conducted by means of Cyclone Leica Geosystems (v.7.3.3) enables to merge point clouds and reduced the number of points. The point elimination is determined mainly by spacing between points. It may leads to loose of important points – representing some essential elements of scanned objects or area. Applying optimization algorithm, especially for complex objects, may help to reduce the number of points without losing the information necessary for proper modeling.

Introduction

Currently, terrestrial laser scanning is used in many fields, for example, to create 3D models of buildings, cities, in research on displacements (ASPERSKI et al. 2010, PILECKI 2013), planning applications (FIDERA et al. 2004), documenting cultural heritage (VOZIKIS et al. 2004, ARMESTO-GONZALEZ et al. 2010,

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BERNAT et al. 2014) and many others. It is a fast and accurate way to acquire reliable data about measured objects. Precise determination of the shape and geometric relationships between objects is strictly related to the measurement of distances and angles between scanner and points from which laser beam bounced off. Measured values are a basic for calculation of *XYZ* coordinates (VOZIKIS et al, 2004, FRYŚKOWSKA, KEDZIERSKI 2010). Modern scanners can measure up to 1,000,000 points per second (Leica Geosystems Brochure Leica ScanStation P20). Acquired a huge number of data points distributed across the observed surface is called a point cloud. It is a final product of scanning. Next to coordinates of points, it also consists of their corresponding intensities. A single point cloud usually does not cover the whole object of interest, therefore a few measurement positions are needed. Obtained point clouds are then registered in order to have all data in single coordinate system. Aspects related to the point cloud registration are presented by BARNEA and FILIN (2008), BRENNER et al. (2008), YANG and ZANG (2014), RABBANI et al. (2007). During scanning not only desired objects are measured, but also a lot of additional elements. Therefore, removing unnecessary data has an impact on efficiency of point cloud processing. User can clear the point cloud(s) manually or can apply tools provided in dedicated for point cloud processing softwares which enable the reduction of point cloud.

Proposal of unification with optimization algorithm

Point clouds become a subject to various types of processing. Essential one is registration – a process of transformation of point clouds into single coordinate system. Registration based on targets, clouds or modeled objects is conducted by means of software dedicated for point cloud processing (e.g. Trimble RealWorks, Faro SCENE, Leica Geosystems Cyclone). Oriented point clouds are then the basics for 3D modeling, creating 2D drawings (plans, sections, profiles), and other purposes. To realize them, a various workflows are proposed, determined by used software and desired goal. In Leica Cyclone, for 3D modeling a solution based on merging point clouds is suggested (VOZIKIS et al. 2004). There are two tools available: merge and unify. Both of them change the separate points clouds into one, however unification can be executed with reduction – low, medium, high, highest or no reduction at all. Point elimination is determined mainly by spacing between them. When object has a complex structure such approach may lead to loosing of significant points. In such situation it is desirable to apply algorithm which adjust reduction to the complexity of the measured object.

Authors propose to use the optimization algorithm presented in the papers Błaszczak 2006, Błaszczak, Kaminski 2007, Błaszczak-Bak et al. 2011, Błaszczak-Bak, Sobieraj 2013. Optimization algorithm was adopted for reduction of TLS datasets and consists of the following steps:

– Defining belts in the *XY* plane parallel to the axis of measurement *Y*.

– Results of laser scanning are arranged in measurement belts in projection onto a plane. On the basis of the calculated azimuth of the belt, the point cloud is fitted in coordinate system. In this system belts in the *XY* plane are defined.

– The choice of cartographic generalization method used to reduce the size of the set of measurement such as Douglas-Peucker (Douglas Peucker 1973), Visvalingham-Whyatt (Visvalingam, Whyatt 1992). The choice of the method is made by user. In this article authors used Visvalingham-Whyatt method.

A general scheme of the generalization is presented in Figure 1.

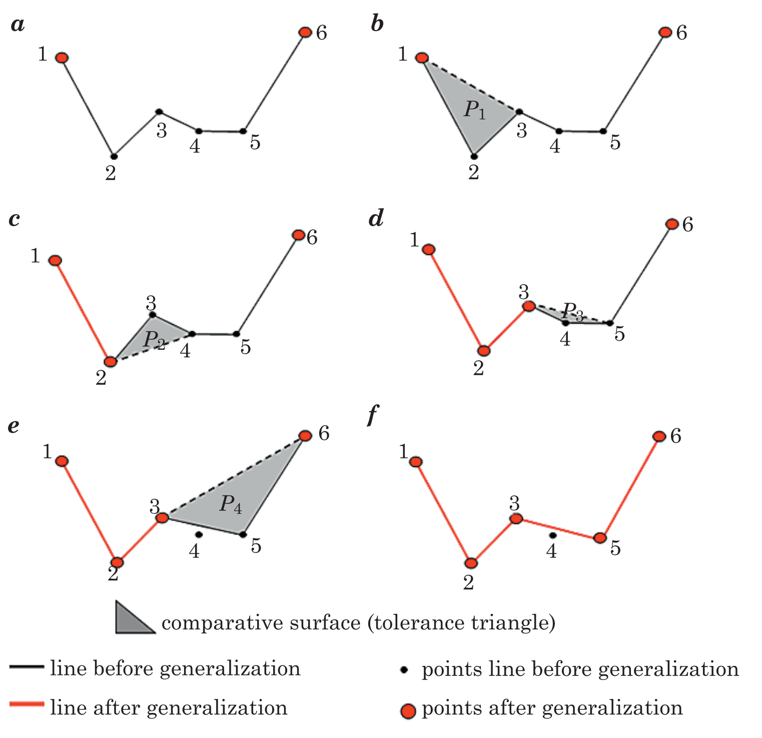


Fig. 1. Stages in line generalization based on comparative surface
Source: Visvalingham, Whyatt (1992).

In each belt (in the *YZ* plane) chosen method of generalization is used. Applying generalization algorithm in *YZ* plane allows to preserve third dimension of the data.

An important step is to choose a belt measurement, as well as the selection of appropriate tolerances in the method. The choice of the tolerances determines the degree of reduction of dataset (number of deleted points).

Material and methods

The optimization algorithm used in this paper was developed and presented in articles by BŁASZCZAK 2006, BŁASZCZAK, KAMINSKI 2007, BŁASZCZAK-BĄK et al. 2011, BŁASZCZAK-BĄK, SOBIERAJ 2013. In mentioned papers algorithm was tested only on ALS dataset. In this paper, authors decided to test it on TLS dataset and compare its efficiency with results obtained by using tools provided in software dedicated for point cloud processing.

In this study laser scanner Leica C10 was used. Its characteristics are presented below:

– speed measurement: up to 50,000 points/s,
– field of view: 360 degrees Vertical, 270 degrees Horizontal
– range <300 m,
– accuracy of the modeled area of >2 mm,
– positional accuracy of >6 mm, distance >50 m 4 mm,
– dual axis compensator ensures the accuracy of measurement,
– built-in camera allows you to take pictures of the scanned object,
– power supply: internal batteries – operating time up to 3.5 hours on one set – allows measurements independent of an external power source,
– memory: built-in 80GB hard disk drive – allows recording data from the whole measurement.

As a research facility building located within the University of Gdansk was used. On the front elevation (north wall) there is a relief. It shows the image of a dragon and a man coal-stoker with a shovel. Points covering this wall became the subject for detailed tests.

Measurement was made on the four positions. Layout of positions is presented in Figure 2.

The unification was carried out for three options:

1) point clouds encompasses simple area/object, here: fragment of relief,
2) point clouds encompasses one object, here: whole relief,
3) point clouds encompasses given/complex area, here: fragment of wall with relief.

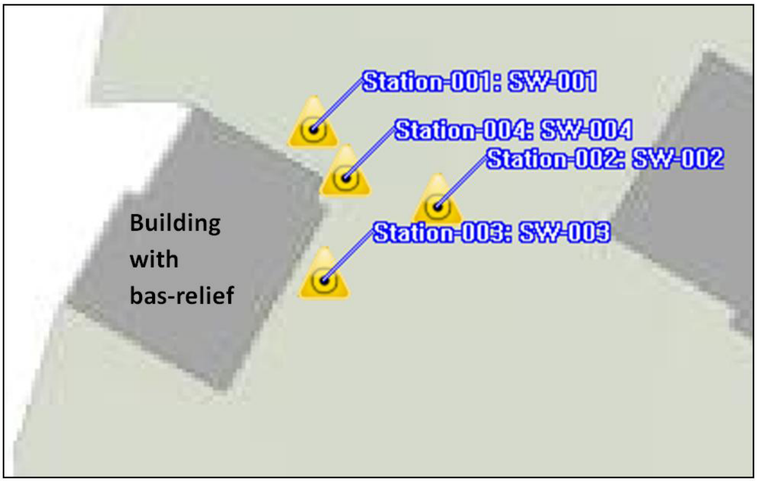


Fig. 2. Layout of scanned positions
Source: own research in Cyclone.

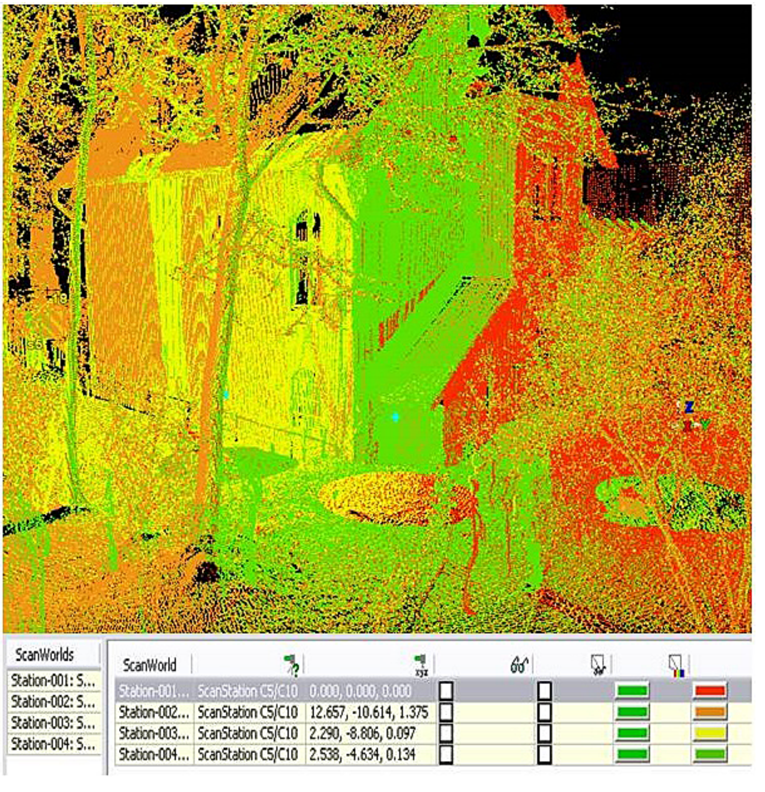


Fig. 3. Obtained point clouds
Source: own research in Cyclone.

Point clouds and the adopted color scheme for each of the sets of measurement are presented in Figure 3.

For each option unification was conducted for two cases: 1) unification based on optimization algorithm, 2) unification with high reduction in Leica Cyclone software.

The influence of optimization algorithm was tested by visual inspection of points distribution for mentioned two cases. Additionally statistical parameter – coefficient of determination (D) was calculated. Coefficient of determination is the measure of model adjustment (the closer to 1, the better the match of the model to another model). It illustrates the degree of match of reduced datasets to a set of original data. To calculate the parameter D in both cases on the basis of reduced sets DTM was generated. The size of the GRID was equal to 2 cm. The coefficient of determination was calculated:

$$D^2 = \frac{\sum_{i=1}^{k}(Z_{\mathrm{DTM}_{\mathrm{ORG}}} - Z_{\mathrm{mean}})^2}{\sum_{i=1}^{k}(Z_{\mathrm{DTM}_{\mathrm{OA}}} - Z_{\mathrm{mean}})^2},\ D^2 = \frac{\sum_{i=1}^{k}(Z_{\mathrm{DTM}_{\mathrm{ORG}}} - Z_{\mathrm{mean}})^2}{\sum_{i=1}^{k}(Z_{\mathrm{DTM}_{\mathrm{URC}}} - Z_{\mathrm{mean}})^2} \tag{1}$$

where:

Z_{mean} – is a mean height calculated from heights of both DTMs, z_i ($i=1, 2..., k$) are heights of the point assumed for creating DTM, k is the size of the subset used for DTM construction,

$Z_{\mathrm{DTM}_{\mathrm{ORG}}}$ – are height of DTM points generated from **ORG**inal data.

$Z_{\mathrm{DTM}_{\mathrm{OA}}}$ – are height of DTM points generated from data obtained after unification with **O**ptimization **A**lgorithm,

$Z_{\mathrm{DTM}_{\mathrm{URC}}}$ – are height of DTM points generated from data obtained after **U**nification with **R**eduction conducted in **C**yclone.

Result and discussion

For each option a different fragments of measuring dataset were chosen. They were visible from all 4 positions. Chosen fragments encompass selected part of relief, the whole relief and part of it with the wall. They are presented in Figures 4, 6 and 8. Next, a unifications were performed. The first one was a unification with optimization algorithm and the second was a unification with high reduction available in Leica Geosystems Cyclone. The results of unifications for each options are presented in Figures 5, 7 and 9.

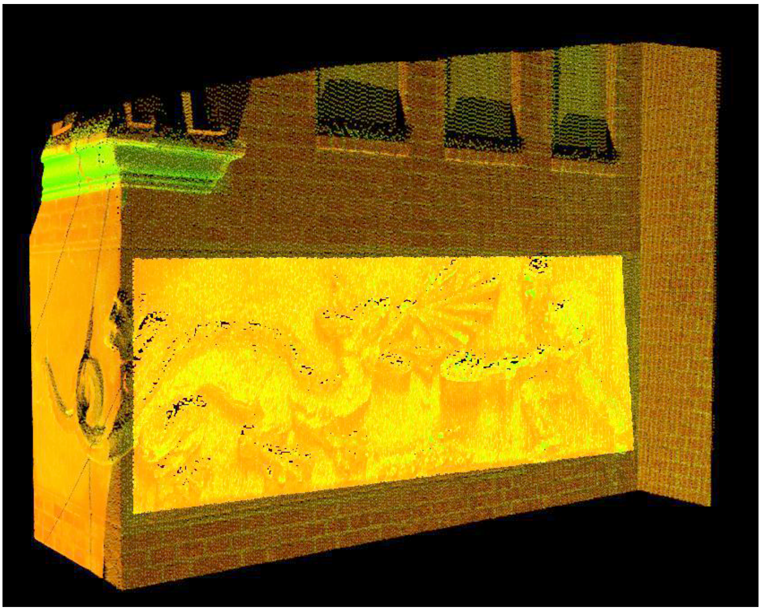


Fig. 4. Option 1 – area chosen for unification
Source: own research in Cyclone.

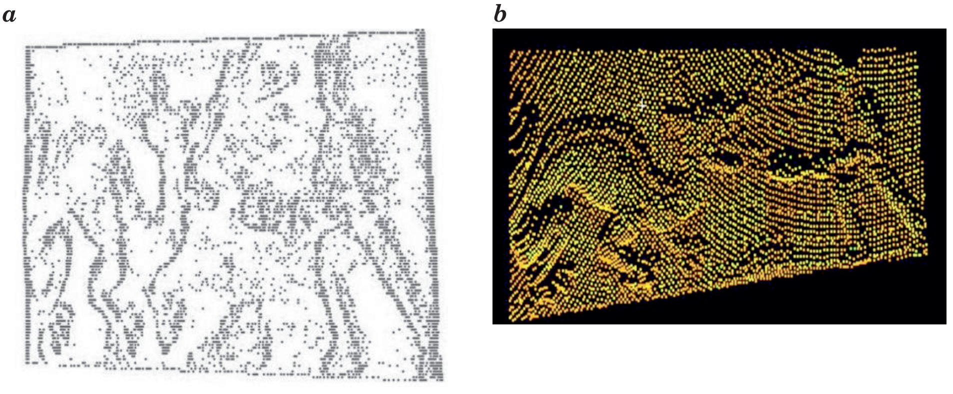


Fig. 5. Option 1 – unification: *a* – own algorithm, *b* – in Cyclone
Source: own research.

To reproduce fragment of relief (e.g. for 3D modeling purpose) distinctive points like outline of man, are essential. During unification relief points were obtained, but some of outline points was lost due to high reduction. Applying optimization algorithm, also with high reduction, but investigating the suitability of each point, the degree of reduction was maintained. Only points from flat surfaces was removed.

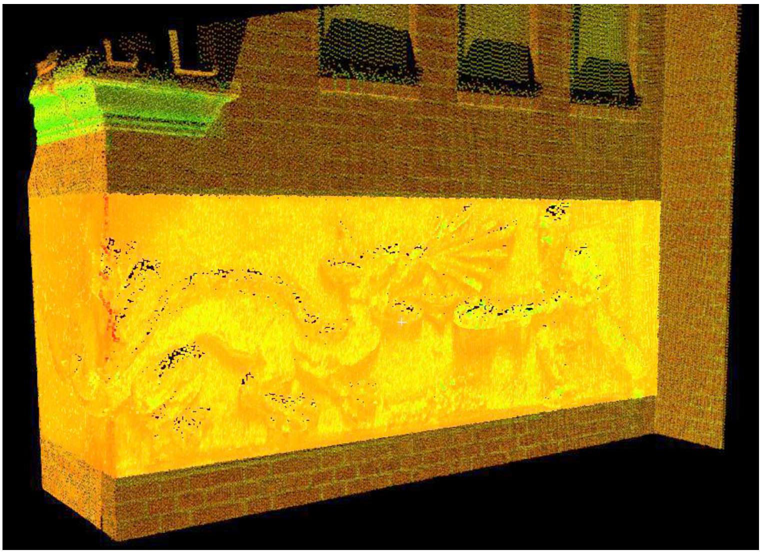
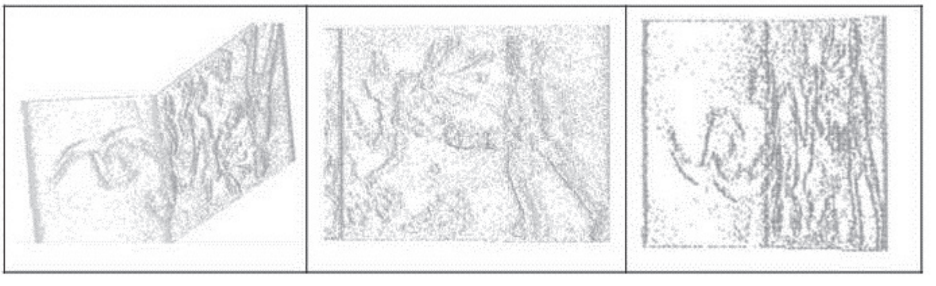


Fig. 6. Option 2 – selected object for unification
Source: own research in Cyclone.

a



b

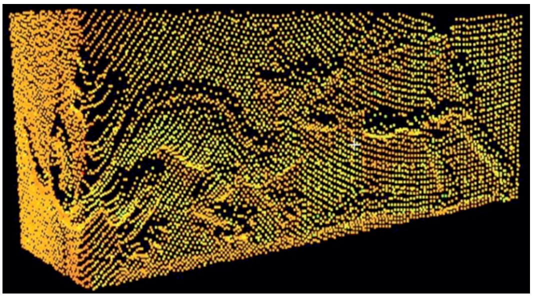


Fig. 7. Option 2 – unification: a – own algorithm, b – in Cyclone
Source: own research.

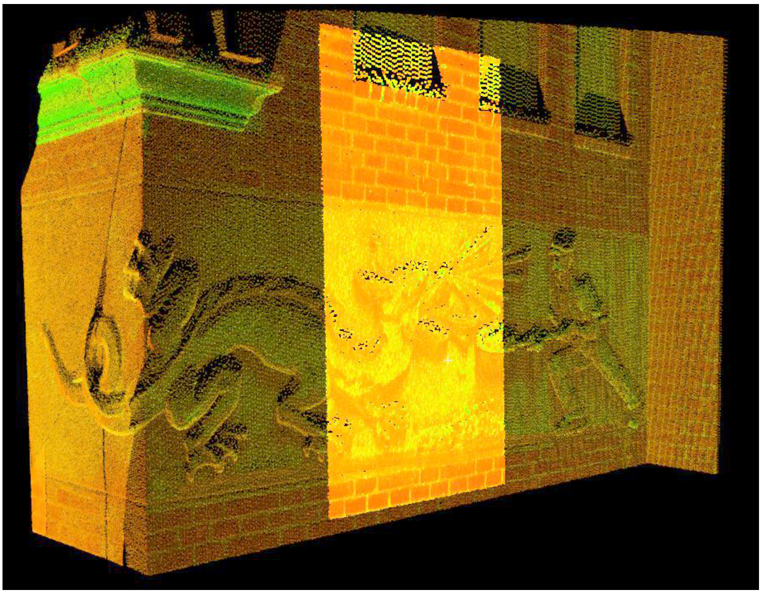


Fig. 8. Option 3 – the selected fragment to unification
Source: own research in Cyclone.

a ***b***

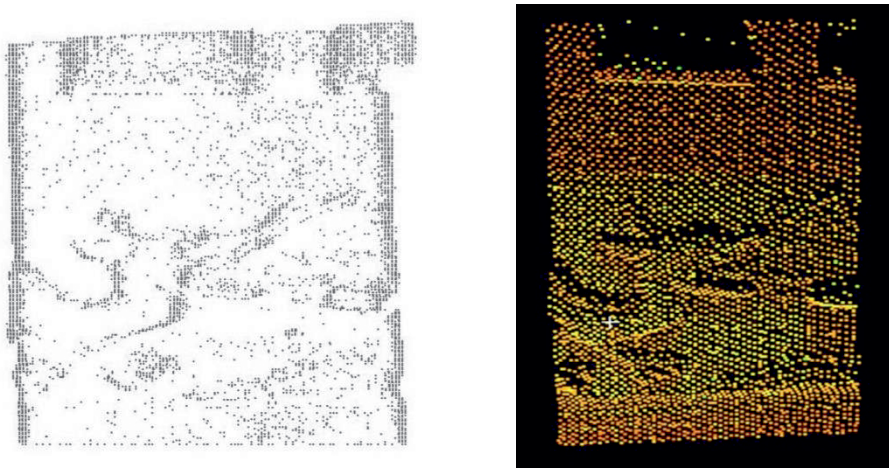


Fig. 9. Option 3 – unification: *a* – own algorithm, *b* – in Cyclone
Source: own research.

The effects of the conducted unifications are presented in Figure 7*a* and 7*b*. Figure 7*a* shows the object from different perspectives. The distribution of points has changed because of applied unification with optimization algorithm.

Unification algorithm with varying degrees of reduction performed the computations in the *YZ* plane. Therefore, in order to compare the bas-relief, it is presented in several versions view.

In Table 1 the results of unifications are presented – the number of datasets after applying unification based on optimization algorithm and unification with high reduction available in Cyclone. There are also values of calculated coefficient of determination (*D*).

Table 1

Results of unifications

Specification	Option 1		Option 2		Option 3	
	number of points	*D*	number of points	*D*	number of points	*D*
Original dataset (points from 4 points clouds)	454,818	–	753,853	–	302,727	–
Unification with optimization algorithm	176,590	0.98	476,325	0.97	179,892	0.98
Unification with a high reduction	198,522	0.94	489,600	0.94	156,600	0.97

For option 1, after conducting unification with high reduction, dataset consisted of 44% of original TLS measuring data. After unification with reduction based on optimization algorithm, obtained dataset comprised of 37% of original data. Coefficient of determination is closer to 1 in the latter case. In option 2, unification with high reduction decreased the dataset and it consisted of 65% of original TLS measuring data. After unification with reduction based on optimization algorithm, obtained dataset comprised of 63% of original data. Coefficient of determination is closer to 1 for dataset obtained after unification with optimization algorithm. For option 3 the number of dataset after unifications with high reduction was less reduced than with unification with optimization algorithm, however the value of *D* indicated that in both cases the match to original is similar.

Conclusions

The article presents a new approach to the problem of point clouds unification. Unification provided in software like Leica Geosystems Cyclone enables reduction of number of points while merging points clouds into one. User can decided is there will be reduction (low, medium, high, highest) or not. As a final result of such unification user obtains one point cloud with various number of points. However, using such unification with reduction may lead to the lost of important data. If the points clouds will be used further, e.g. for 3D modeling, there should be all significant points in dataset. In this paper authors propose to apply optimization algorithm based on cartographic generalization method in unification with reduction. The use of this algorithm enables to reduce the number of points in the point cloud with varying degrees of reduction in different areas. Thus, points, which are not essential in the generation process (e.g. modeling) will be removed from the measurement dataset. The reduction is not random, and each point is tested prior to removal because of its usefulness. Optimization algorithm is designed to leave a larger number of points in the places where there is such a need, such as refraction, embossed edges etc. During tests it was seen as a higher density of points in areas with more details like the outline of figures in relief. Within regular surfaces it leaves smaller, but a sufficient for modeling number of points. Unification with optimization algorithm has no negative influence on information content of dataset, what was confirmed by calculating D. It also should be noted that the user can determines the degree of reduction by identifying relevant parameters of optimization. Proposed solution can be a good and effective alternative for unifications provided by commercial software.

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