An example of using the OptD method to optimization of point clouds in the buildings diagnostics

Czesław Suchocki[1], Wioleta Błaszczak-Bąk[2], Marzena Damięcka-Suchocka[3], Marcin Jagoda[4], Andrea Masiero[5]

[1] Koszalin University of Technology, Faculty of Civil Engineering Environmental and Geodetic Sciences, Śniadeckich 2, 75-453 Koszalin, Poland, czeslaw.suchocki@tu.koszalin.pl

[2] University of Warmia and Mazury in Olsztyn, Institute of Geodesy, Oczapowskiego 2, 10-719 Olsztyn, Poland, wioleta.blaszczak@uwm.edu.pl

[3] Koszalin University of Technology, Faculty of Civil Engineering Environmental and Geodetic Sciences, Śniadeckich 2, 75-453 Koszalin, Poland, marzena.damiecka@wilsig.tu.koszalin.pl

[4] Koszalin University of Technology, Faculty of Civil Engineering Environmental and Geodetic Sciences, Śniadeckich 2, 75-453 Koszalin, Poland, marcin.jagoda@tu.koszalin.pl

[5] Interdepartmental Research Center of Geomatics (CIRGEO), University of Padova, via dell'Università 16, 35020 Legnaro (PD), Italy, masiero@dei.unipd.it

Key words: *OptD method; TLS; optimization of the dataset; defect detection*

ABSTRACT

Terrestrial Laser Scanner (TLS) measurements can be used to assess the technical condition of buildings and structures: in particular, very high resolution TLS measurements should be taken in order to detect defects on building walls. This consequently results in the creation of a huge amount of data in a very short time. Despite high resolution measurements are typically needed in certain areas of interest, e.g. to detect cracks, reducing redundant information on regions of low interest is of fundamental importance in order to enable computationally efficient and effective analysis of the dataset. In this work, data reduction is made by using the Optimum Dataset (OptD) method, which allows to significantly reduce the amount of data while preserving the geometrical information of interest area. As a result, more points are kept on areas corresponding to cracks and cavities than on flat and homogeneous surfaces. This approach allows for a thorough analysis of the surface discontinuity in building walls. In this investigation, TLS dataset was acquired by means of the time-of-flight scanner Riegl VZ-400i. The results obtained by reducing the TLS dataset by means of OptD show that this method is a viable solution for data reduction in building and structure diagnostics.

I. INTRODUCTION

Terrestrial laser scanning (TLS), also called high-definition surveying (HDS), is a simple method for high accuracy mapping of real objects. TLS is a non-contact method for rapidly capturing a rich amount of details of the measured object. The most common applications of TLS are geodetic, structural, and civil engineering measurements, such as topographic surveys *et al*., 2013), landslide monitoring (Kasperski *et al*., 2010),(Suchocki, 2009), monitoring and diagnostic of structures and buildings (Liu, Chen and Hauser, 2011),(Suchocki and Katzer, 2018b),(Suchocki *et al*. 2008), roadway surveys (Pu *et al*., 2011)(Guan *et al*., 2014), cultural heritage documentations (Yastikli, 2007),(Pavlidis *et al*., 2007).

Cultural heritage sites, which are spread all around the World, should be protected, monitored and renewed. The use of a proper remote sensing documentation technique is of fundamental importance in order to obtain 3D models of cultural heritage sites with high accuracy and details, but reducing the risk of damages. To this aim, the TLS technology can be conveniently carried out. Indeed, it provides the ability to collect data with high density at speeds of above 1 million points per second with millimetre accuracy. Furthermore, TLS can register the radiometric information of returned laser beam signal, so-called intensity. The intensity value can be used for defect detection on wall surfaces, e.g. cracks, cavities (Armesto-González *et al*., 2010), *(Suchocki, Jagoda, et al*., 2018) or change humidity saturation and moisture movement in building (Suchocki, Katzer and Rapiński, 2018)(Suchocki and Katzer, 2018a). Intensity information can be a useful tool to assess the technical state and the need of restoration of the historical buildings (Li and Cheng, 2018).

In recent years, TLS has gained popularity in several applications related to cultural heritage conservation. Typical symptoms of the poor state of conservation of historical buildings are cracks, cavities and various discontinuities on the building surfaces. Therefore, collection of high-resolution point clouds on cavities and cracks is very important to monitor conservation status of buildings. The ability to test the geometry of the building and simultaneously detect visible cracks and cavities is very useful during the technical inspection of a building.

The need of detecting also minor defects on the surfaces of walls imposes the acquisition of TLS measurements at very high resolution. However, this often leads to very large datasets, which are consequently difficult to efficiently process with commercial software. This motivates the usage of automatic optimization methods for reducing the size of the above-mentioned datasets.

Typically data reduction is performed by using a random method which in consequence causes the loss of important information.

Point cloud data reduction is often achieved by randomly subsampling the dataset. Despite this method is clearly simple and computationally extremely efficient, it does not consider the possible consequences of such subsampling, hence potentially leading to the loss of important information. Differently, this work considers the use of the Optimum Dataset (OptD) reduction method to reduce the number of points without the potential loss of useful information cardinality while carefully taking into control the potential loss of useful information, e.g. the method is expected to properly reduce the number of points on flat surfaces while keeping points on defect/damaged areas (cracks and cavities).

The OptD method was typically used to reduce a large dataset of LIDAR measurement for building digital terrain model (Błaszczak-Bąk, Sobieraj-Żłobińska and Kowalik, 2017). Instead, the OptD method has not been used to optimise point clouds for building and structure diagnostics so far: this paper investigates the potential of the usage of OptD method to this aim, and presents the obtained results on scans of a historical building.

II. Theoretical background of OptD method

OptD method was originally proposed in (Błaszczak-Bąk, 2016 and Błaszczak-Bąk, Sobieraj-Żłobińska and Kowalik, 2017) with the aim of decreasing the size of a measurement dataset while preserving most of the information contained in such data (Bauer-Marschallinger, Sabel and Wagner, 2014).

The OptD method is different from the reduction of height data conducted by DTM generalization (Bakuła, 2014) because it is used in the pre-processing stage, without the need to build DTM. The OptD method starts the processing from determination of the optimization criterion (f). This parameter can be for example percent of points or standard deviation. OptD method works in two planes. In the first steps the OptD method determine the initial width of the measuring strip (L) in the horizontal plane . Then the selection of points for each measuring strip begins and in each strip the cartographic generalization method is used but this time in vertical plane (Douglas and Peucker 1973). Very important in this stage is right choice of tolerance parameter (t). Each measuring strip is processed separately. The last stage is verification, whether obtained dataset fits the specified optimization criterion. If so, the reduction process is completed. If not, suitable steps are repeated.

The use of OptD methods has a positive impact on the following aspects:

- Geometry visibility. Improvement of visibility and readability of the measured details. After applying OptD it is possible to better distinguish object shapes that might originally be hard to be seen due to the large amount of data (W. Błaszczak-Bąk, Sobieraj-Złobińska and Wieczorek, 2018);
- Processing time. Reduction of the dataset in the pre-processing stage enables less labor-intensive and time-consuming computations of e.g. DTM, 3D modeling (Błaszczak-Bąk, Sobieraj-Żłobińska and Kowalik, 2017).

The OptD method works in such a way that it keeps more points in places where there is a large variation due to the examined characteristic, e.g. height, intensity. On the other hand, less points are preserved where the object shape is very smooth e.g. where it can be locally well approximated with a planar surface. Consequently, the application of OptD produces point clouds with non-homogeneous densities: degree of data reduction is highly dependent of the local object complexity (i.e. of the information contained in such area of the 3D model).

Differently from simple subsampling methods, OptD checks the usefulness of each point in the model: a tolerance parameter is used to determine whether a point should be preserved or discarded. The OptD method is rather automatic, i.e. the user only selects the optimization criterion. Actually, just one criterion shall be used in the OptD-single variant (Wioleta Błaszczak-Bąk, 2016), which is the one adopted in this work, whereas a multiple-criteria optimisation is implemented in the OptD-multi case (Wioleta Błaszczak-Bąk *et al.*, 2017).

Figure 1 summarizes the workflow of the OptD-single method taking into account all the parameters that affect the reduction results.

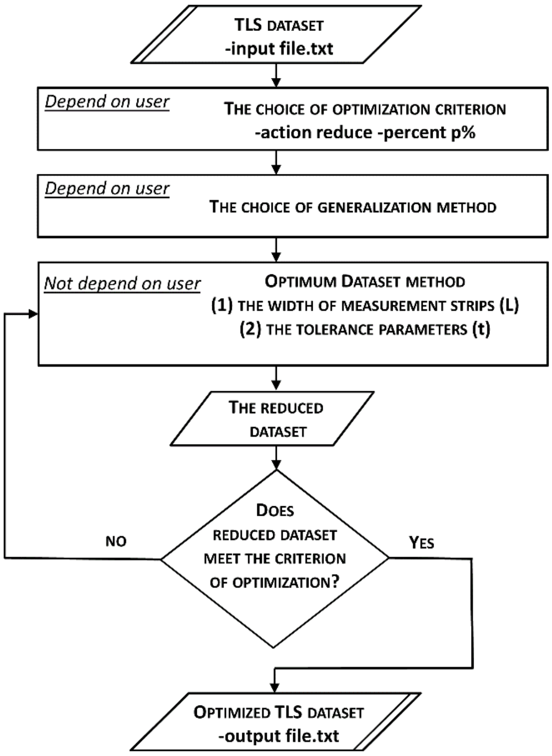

Figure 1. OptD workflow

Figure 2. The research object 1- wall with damaged plaster

III. Scope of Work

A. *Object of research and used equipment*

In this work, a time-of-flight terrestrial laser scanner Riegl VZ-400i was used. This TLS uses a narrow infrared laser beam. Laser pulse repetition is from 100 kHz to 1200 kHz. The maximum measurement range of this TLS is up to 800 meters for laser pulse repetition rate 100 kHz. The scanner works with a maximum measurement rate of 500,000 pixel/sec for laser pulse repetition rate 1200 kHz. The laser beam diameter is approximately 3.5 mm and laser beam divergence is equal 0.35 mrad. Accuracy of conformity of a measured quantity to its actual value is approximately 5 mm.

The object of research was the building of an old tobacco factory in Cracow. The building is part of the *Dolne Młyny* complex, which is under the supervision of the conservator. The interior part of the building has been restored. The outside part of the building is characterized by poor conservation state (Figure 2). The *Dolne Młyny* complex was enriched with a prestigious club offering a rich entertainment and cultural program. The club refers to the legendary New York Studio 54 (West 54th Street in Manhattan). A part of wall with damaged plaster (Figure 2) and concrete structural element with cracks (Figure 3) were used to carry out the tests. Measurements were conducted by TLS from distances of 10 m, with 1200 kHz laser pulse repetition rate. The angle measurement resolution was set on the scanner at horizontally 0.01 deg. and vertically 0.01 deg. respectively.

Figure 3. The research object 2- concrete element with the cracks

B. *Research and results*

The RiSCAN PRO software was used for the pre-processing of data. The CloudCompare software was used to visualize and present the reduced dataset.
Detailed characteristics of obtained datasets are provided in Table 1.

Table 1: Characteristics of tested samples

Sample	Dimensions [m]	No points	Nº points/ 0.01 m^2
wall with damaged plaster	1.50 · 0.90	2,377,449	170
concrete element with cracks	2.30 · 0.38	762,480	90

The TLS datasets were processed by means of the OptD-single method. The percentage of points to be kept after the data reduction was assumed as optimization criterion in the OptD. During the processing of the OptD-single method, the Douglas-Peucker generalization method was used (Douglas and Peucker, 1973). In OptD-single method six different criteria have been adopted: 20%, 10%, 5%, 2%, 1% and 0.5%. To meet accepted criteria the appropriate parameters were selected.

Table 2 and Table 3 report the parameter values used by OptD to satisfy the optimization requirements (such values depend only on the specifically selected optimization criterion).

Table 2: Parameters adopted by the algorithm - wall with damaged plaster

p%	20%	10%	5%	2%	1%	0.5%
L [m]	0.001	0.001	0.001	0.001	0.001	0.001
t [m]	0.002	0.003	0.004	0.009	0.016	0.031
iteration	9	14	14	13	11	10

Table 3: Parameters adopted by the algorithm - concrete element

p%	20%	10%	5%	2%	1%	0.5%
L [m]	0.001	0.001	0.001	0.001	0.001	0.001
t [m]	0.002	0.003	0.005	0.013	0.022	0.036
iteration	15	13	13	12	12	10

The results of the OptD-single method optimization of the point clouds in the test areas 1 and 2 are presented in Figure 4 and Figure 5 respectively.

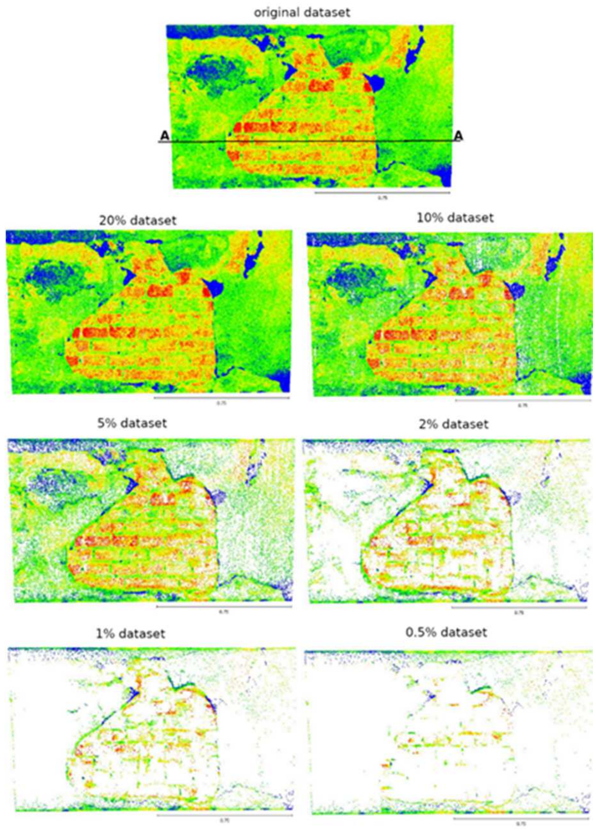

Figure 4. Results of processing based on OptD-single method for test area 1

The main advantage of the OptD method is low data reduction on areas corresponding to defects (cavities, cracks, other surface discontinuities) and large data reduction on regular areas (without defects). This can clearly be seen by means of visual evaluation in the presented examples (Figure 4 and Figure 5). For instance, the number of points in the 2% and 1% datasets in Figure 4 have been largely reduced on the flat areas, while leaving enough points on the defects of the wall. Since the number of points kept on the damaged areas is still high, it allows to make a proper diagnosis of the conditions of such area.

A similar observation can be repeated for 5%, 2% and 1% datasets in Figure 5.

It is also worth to be noticed that in both the cases (see Figure 4 and 5), the 0.5% dataset does not allows a proper diagnosis and detection of defects. This is a direct consequence of the dramatic data reduction imposed in such cases and of the specific behaviour of the OptD algorithm, which always preserves a significant amount of points on the borders of the considered area, e.g. 0.5% dataset in Figure 5.

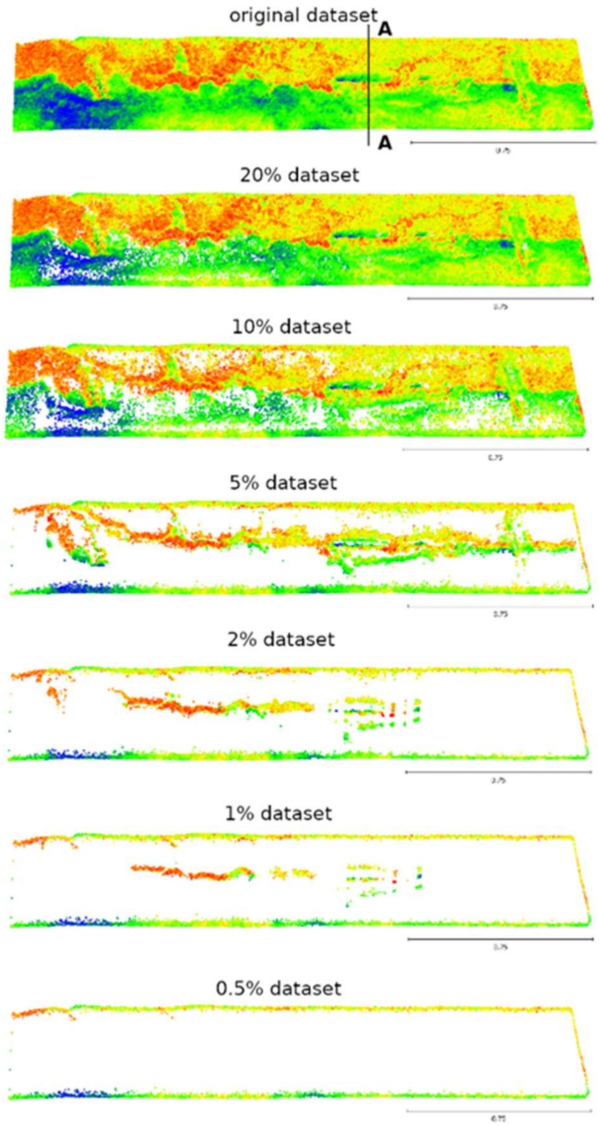

Figure 5. Results of processing based on OptD-single method for test area 2

AA profiles were made for both the cases to carefully analyze the obtained results, which are shown in Figure 6 and 7. The profiles show strips of 0.008 m width (see Figure 4 and Figure 5).

It is worth to notice that points close to sudden profile changes should be preserved by the data reduction method to properly maintain the possibility of defect detection on the wall surface. Positions corresponding to such sudden changes are marked with dashed lines in Figure 6 and 7 to ease the readability of these figures.

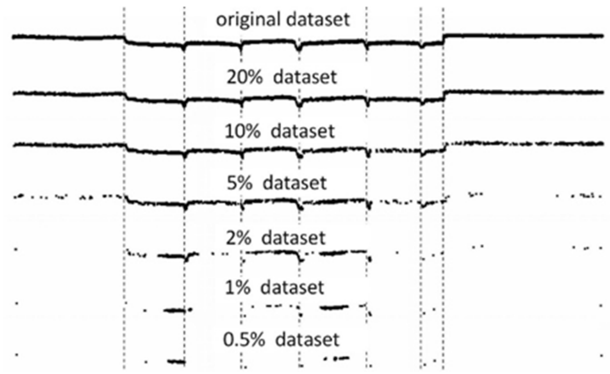

Figure 6. Profiles for test area 1

In Figure 6 a dashed line was located in a mortar layers. In most cases the mortar layers have been damaged. By analyzing the individual profiles, it can be concluded that the OptD reduction method left more points in the above-mentioned places than on the flat surfaces.

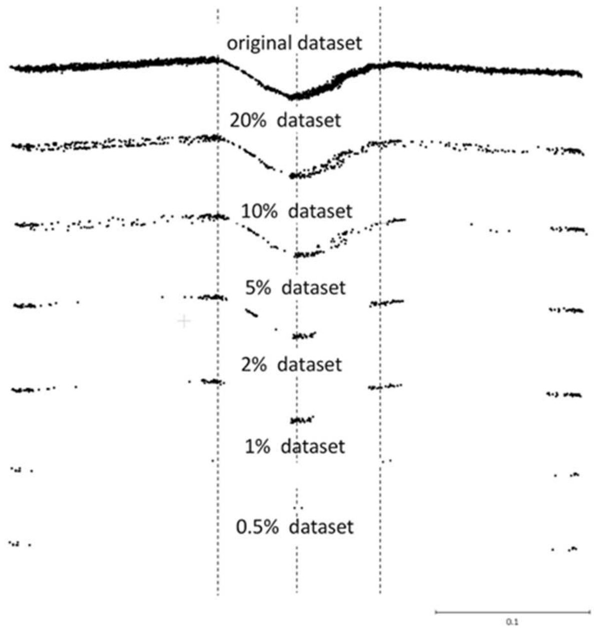

Figure 7. Profiles for test area 2

The profiles shown in Figure 7 corresponds to a defected area in the concrete element. As shown in this figure (e.g. 2% dataset), OptD method clearly kept a larger amount of points on areas associated to profile variations, which are those more informative for detecting defects.

Since OptD keeps a larger number of points on defected areas, it is quite clear that it allows high data reduction while still preserving the possibility of detecting cavities and cracks.

IV. Conclusions

The paper presents the application of the OptD method for the optimized size reduction of point clouds in the diagnosis and monitoring of historical buildings. Results reported in this paper show that, thanks to its careful optimized point selection, the use of OptD allows to obtain a significantly smaller dataset while also highlighting defects, discontinuities in the wall with damaged plaster and in the concrete element.

Based on the results obtained in the considered case studies, the following conclusions can be drawn:

- The reduced dataset obtained with OptD has a significantly lower point density on regular areas (wall without defects) than on defects (cavities and cracks).
- Obtained results show that OptD can be effectively used for optimizing cloud points from diagnostic measurements buildings and other structures.
- The results of this work indicate the possibility of using OptD as a tool for easing the detection of defects in buildings and structures. Our future work will be dedicated to the investigation of this aspect.

V. Acknowledgements

The authors would like to express their gratitude to the National Science Center (PL - Narodowe Centrum Nauki), Poland for the financial support for this study under Project Miniatura 1 (No: DEC-2017/01/X/ST10/01910).

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