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TIN DATA OPTIMIZATION FOR SHAPE EXTRACTION FROM TERRAIN LASER SCAN MEASUREMENT

OPTYMALIZACJA TIN POZYSKANEGO ZA POMOCĄ SKANERÓW LASEROWYCH DO BUDOWY MODELU

A b s t r a c t

Three consecutive phases of laser scanning technology viz.: data acquisition, pre-treatment of acquired data and TIN optimization and shape extraction have been presented in the paper on the example of medieval church in Lomello near Pavia in the North of Italy. A terrain laser scanner Riegl LMS-Z420 and commercial software RapidForm for acquisition and data pretreatment has been used. For the purpose of shape extraction an optimization of the TIN model is needed to eliminate points that are not necessary for shape extraction. Model optimization was written as a new algorithm to select points cloud and redefine TIN triangles. It was written in MatLab language. In the last phase the shape of the model has been extracted from the optimized TIN model. The extraction algorithm was written in MatLab language as well.

Keywords: *laser scanning*, *data processing*, *TIN optimization*, *shape extraction*

S t r e s z c z e n i e

Kolejne etapy technologii skaningu laserowego, tj. pozyskiwanie danych, wstępne opracowanie danych i optymalizacja modelu TIN oraz wyznaczenie kształtu zaprezentowano na przykładzie opracowania średniowiecznego kościoła w miejscowości Lomello w północnej części Włoch niedaleko Padwy. Przy pozyskiwaniu danych zastosowano skaner laserowy Riegl LMS-Z420, a do wstępnego opracowania modelu TIN – firmowe oprogramowanie RapidForm. Główną częścią artykułu było wyznaczenie na potrzeby optymalizacji kształtu obiektu, do czego posłużył algorytm optymalizujący model TIN: eliminujący punkty zbędne oraz definiujący w inny sposób siatkę trójkątów. Algorytm zapisano w języku MatLab. Ostatni etap działań stanowiło opracowanie algorytmu w języku MatLab w celu wyznaczenia kształtu obiektu.

Słowa kluczowe: *skanowanie laserowe*, *opracowanie danych*, *model TIN*

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1. Data acquisition

Three consecutive phases of laser scanning technology viz.: data acquisition, pretreatment of acquired data and TIN optimization and shape extraction has been presented in the paper on the example of medieval church in Lomello near Pavia in the North of Italy (Fig. 1). For data acquisition Riegl LMS-Z420 terrain laser scan was used. It is equipped by a system for high speed laser definition acquisition and digital camera on the top of the instrument to colour point cloud. In this case it was Nikon D100 with a calibrated objective. The camera was connected and controlled by the computer. The scan process was controlled by software Riegl Riscan provided with the scanner.

Fig. 1. On the left – the Lomello Baptistery, object of acquisition. On the right – a reflective marker
Rys. 1. Z lewej – Lomello Baptistery – obiekt badań, z prawej – znaczek badawczy

To carry out a stage of data acquisition a number and position of scan points has been established as well as scan step and distance from instrument to object. These parameters determine the final use of acquired data. Some small reflection markers on the scanned object were established as the data acquaintance have been taken from two scan stations. Markers were automatically identified by a software because of their high reflectivity. To integrate two different clouds of points we have to observe in two scans more than three markers. The join procedure of 3D rototranslation produces uniques clouds of points in one system.

The scanning was carried out with an angular step equal to 20 mgon. As the distance between instrument and structure was 15 m we have got one acquired point every 5 mm on the object. This density grid meets requirements of presented investigations.

Firstly, a low definition scan, so called pre-scan, is carried out to establish precisely a scan range. The pre-scan produces a cloud of points of all instrument range, from 0° to 80° for vertical angle and from 0° to 360° for horizontal angle. Basing on the pre-scan by means of the control software a high definition scan area is presupposed. Two different scans have been taken from station number one. The second scan from the first station was necessary to acquire the data of the little tower which was not visible from the first scan.

From the second station only one scan was done for parts of the structure which was not visible from first scan station.

Result of scanning:

Scan 1: acquired points 13 190 406 – large scan area,

Scan 2: acquired points 1 214 014 – the little tower on the church,

Scan 3: acquired points 4 718 305 – from second scan station.

In scanning process the instrument acquires point position x, y, z coordinates and points reflectivity. The last parameter depends on a power of return laser ray. Materials like glass or bright metal do not disperse a lot of laser ray power because they have high reflectivity. Thanks to reflectivity information it is also possible to get a grey scale representation of acquired points. After every single scan the instrument acquires RGB information with the digital camera. The scanner automatically takes pictures of all work range (0°–360°), this photos have a presupposed overlap, in presented case it was 30%.

2. Data pre-treatment

Pre-treatment of acquired data consists of:

– cloud of point registration to obtain one unique cloud of point,
– cloud of point colour,
– data filtration.

Registration of different clouds of points consists of 3D rototranslation without scale change. This procedure is based on the equation

$$\begin{pmatrix} X_1 \\ Y_1 \\ Z_1 \end{pmatrix} = \begin{pmatrix} X_u \\ Y_u \\ Z_u \end{pmatrix} + R \cdot \begin{pmatrix} X_2 \\ Y_2 \\ Z_2 \end{pmatrix} \tag{1}$$

Where:

X_1, Y_1, Z_1 – point coordinates in the first scan,

X_2, Y_2, Z_2 – point coordinates in the second scan,

X_u, Y_u, Z_u – coordinates of second reference system from first reference system,

R – rototranslation matrix.

The research of counterpart points is completed automatically thanks to reflection marker. The algorithm can identify this points thanks to their very high reflectivity. In this phase only correct selection of this particular points due to possible errors are controlled. For example a glassing plane like a window have a high reflectivity and it can be taken like a marker. It is a source of gross errors, but it is easy to identify this kind of point in automatically finding list and eliminate it. After obtaining a unique cloud of points it is possible to transfer the colour information from pictures to points cloud (Fig. 3). The pictures should be taken with calibrated camera to control camera distortions. As we also know a relative position behind the centre of the camera and the centre of the scanner we can transfer RGB information using the collinear equations where all parameters of the rototranslation matrix can be determinated. This procedure runs automatically, an operator controls only the right definition of the counterpart points. Corrections are possible thanks to manual selection of wrongly chosen or not precisely selected counterpart points. This kind of error depends on the camera position on the instrument. Camera is mounted using a special support but little position change in montage process in unavoidable.

Fig. 2. View of pre-scan result
Rys. 2. Wyniki skanowania wstępnego

Fig. 3. The view of point cloud taken from second scan station, after and before the colour process
Rys. 3. Wyniki skanowania właściwego w postaci „chmury” punktów
po i przed uwzględnieniem barwy

The last step of pre-treatment stage is data filtering, the most important and complicated pre-treatment data procedure. Acquired data are in most case infected by errors. This problem is linked with the measure technology. A laser scan is defined as a high speed total station, points are acquired by spherical coordinates, by determining two angles and one distance. Angles are determined by high precision mechanical instrument, lengthes by a laser distancer. Angles are measured with higher precision than distances. For this reason, measure noise problem is in to the distance measure and mostly in laser ray divergence. Instrument Riegl LMS-Z420i has a measuring precision of angles equals to 0,002°, at 50 m distance it corresponds to 1,7 mm. Distance precision is 10 mm in single spot mode. Moreover laser ray divergence is 25 mrad, with an acquisition distance of 50 m, it means that an impact area of laser ray equals to 12,5 mm^2. That is why this problem can be classified like a 2D½ because for every couple of angles, vertical and horizontal, only one point measured by altitude exists (this correspond to a distance). This problem was not analysed by the author in details, but pre-treatment procedure was used to obtain data for next stage. For data filtering a software LRS created by Politecnico di Torino was used. To import the cloud of points to LRS the TXT format was used. This program uses the same, aforementioned, theoretical approach to data filtration. All point are divided by: corrects, gross errors, outliers (Fig. 5). After the classification gross errors and outlier points are eliminated and the result was a more light could of points.

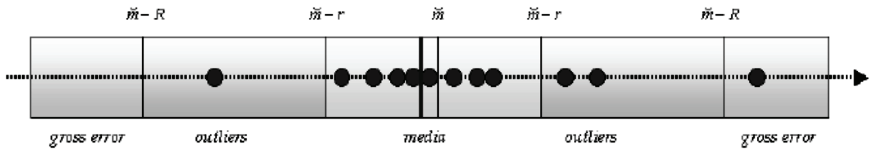


Fig. 4. Scheme of points classification using medial value in filtration process
Rys. 4. Klasyfikacja punktów w procesie filtracji

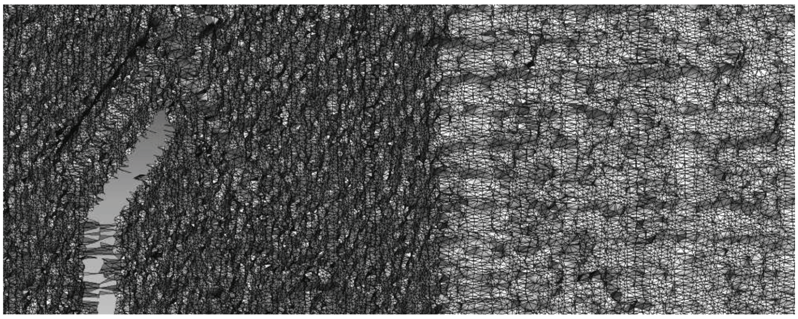


Fig. 5. TIN model view. Model discontinuity in hidden part of build
Rys. 5. Model TIN. Fragment z zacienioną częścią

After pre-treating data are ready to make triangle model of object. Commercial software RapidForm for 3D modelling was used for this purpose. To obtain good triangle model the software suggests that some parameters are to be controlled. In presented case the author assumed that a border length of triangle can not exceed 5 cm. This size was derived from different test with different value of maximum length. Other construction bond was angle between a triangle face normal and the scan direction (direction of laser ray). This parameter was calibrated with different test, and the value of 80° value was assumed. Where these two parameters were not fulfilled, faces were not created by the software. Obtained model was not perfect. There were some discontinuity and holes in triangle net because in the case of hidden part of building the TIN software could not generate triangles respecting bond parameters.

Completed TIN model was exported in OBJ format. The OBJ is a geometry definition file format open and has been adopted by other 3D graphics application vendors, so it can be imported and exported from in most 3D applications. For the most part it is an universally accepted format. The OBJ file format is a simple data-format that represents 3D geometry by a list of vertex and a list of vertex that compose polygons. It is possible to have information about faces normal and textures. In presented case the OBJ file includes only a list of vertex (X, Y, Z coordinate) and a list of triangles vertex. In all line of faces list there are 3 vertex as there are only triangle faces in TIN model.

3. TIN optimization

After having pre-treated the TIN model presents some problems. First of all there are too many points for shape description. This problem derives from the scan setting during the data acquisition. In laser scan procedure we can only set angular step between two acquired points. To acquire data of all details and their shapes, it was necessary to do a very high definition scan. But if the object is of regular shape, for example a plane wall, we get too many points in primitive shape extraction prospective. The TIN model may suggest that points acquired from a plane object like a wall are not from one plane (Fig. 6). This problem was assumed as a form of noise, although, on the other hand, the acquired object is not composed of perfect plane elements. A brick plane wall is not really plane.

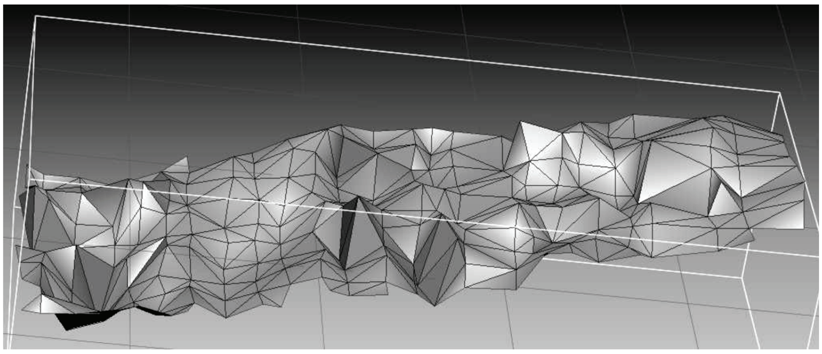


Fig. 6. Particular view of TIN model of plane wall. There are 243 points and 414 faces
Rys. 6. Model TIN ściany złożony z 243 punktów i 414 powierzchni elementarnych

There are two purposes of optimization. Firstly, to eliminate irrelevant points which are out of the scanned shape and to smooth the model. Different commercial software can be used to achieve that results more or less succesfully. At the beginning the 3dsMax (by Autodesk) application was used. In 3dsMax it is possible to import a TIN model and make some operation on it, also smoothing. Parameters for smoothing in this case are the angles between two adjacent faces. After some tests we decided that the better way is to adopt a new algorithm where we can completely control parameters as we need.

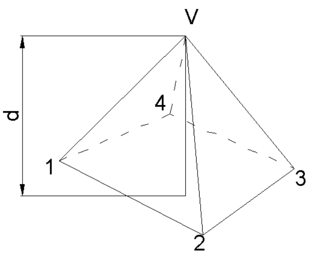


Fig. 7. Scheme of simplification criteria. V – analyzed point, d – parameter of simplification
Rys. 7. Kryteria uproszczenia modelu. V – analizowany punkt, d – parametr uproszczenia

According to the author a good way to analyse the TIN model is an analysis of irregular pyramidal configuration of points as it is shown in the Fig. 7.

The algorithm proceedes point by point creating a pyramid configuration, then taking into consideration *d* length two cases are analysed:

– if $d \geq d_{max}$, point *V* is deleted and faces are redefined,
– if $d < d_{max}$, point *V* is not deleted and configuration remains the same.

The d_{max} value is defined by user at the begin of optimization.

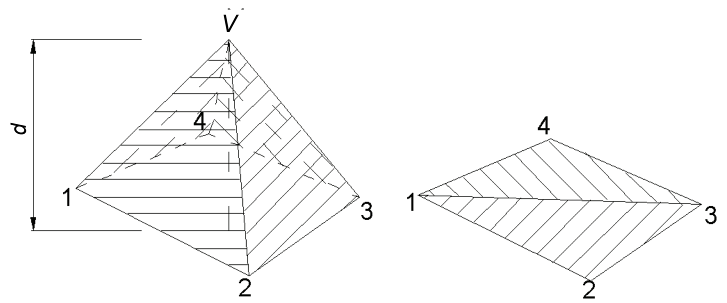


Fig. 8. Scheme of faces redefinition. Point *V* and faces 1V2, 2V3, 3V4, 4V1 were deleted and algorithm make new base faces 124 and 143
Rys. 8. Tworzenie nowej uproszczonej powierzchni wg algorytmu

In the first case the *V* point and lateral faces of the pyramid are eliminated and algorithm generates a new base triangles using the Delanay method. From the other side it is not possible to simplify all points configurations. TIN model borders can not change shape, so border configuration has to remain without any simplification. To recognize this kind of configuration the algorithm uses the following method.

If *V* is the analyzed point the application finds the base points of the configuration and faces where *V* point appears. Then the following control is carried out.

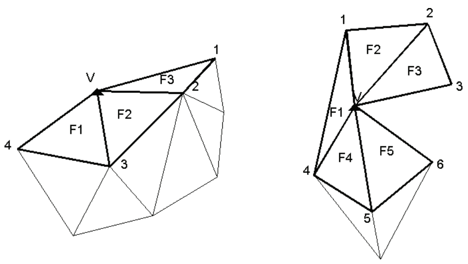
if $V \in n_{faces}$ with $n_{p\ base} > n_{faces}$ border configuration or not able to simplification

if $V \in n_{faces}$ with $n_{p\ base} = n_{faces}$ it is enable to simplification

where:

V – examined point,
n_{faces} – number of faces where *V* appears,
$n_{p\ base}$ – number of base points of examined configuration.

Fig. 9. Scheme of not treatable configurations. On the left a border configuration, on the right a configuration with a discontinuity
Rys. 9. Schemat konfiguracji TIN z granicą i nieciągłościami



The control allows to differ configuration able to be optimized from the case which have to remain without changes. The changes are not possible in the case of borders. In the case of discontinuity this choice simplifies configuration a little. In the case of a hole in TIN model it is possible to write a procedure to repair the problem, but it absorbs too much time.

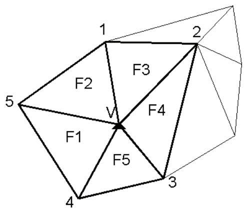


Fig. 10. *V* point appears in the same number of faces (five), like base points number (five)
Rys. 10. Dla punktu *V* liczba powierzchni elementarnych i punktów sąsiadujących jest równa

Summing up: the stages of the presented algorithm are: TIN data load, data organization, configuration researching and simplification, output of optimized TIN. The most important part of the program is the data organization. Data are organized by three matrix. Vertex – **V**, faces – **F** and index – **I**.

$$\underset{n,3}{\mathbf{V}} = \begin{bmatrix} x_1 & y_1 & z_1 \\ x_2 & y_2 & z_2 \\ \vdots & \vdots & \vdots \\ x_n & y_n & z_n \end{bmatrix} \tag{2}$$

The vertex matrix is $n \times 3$ in dimension, n is the number of points (2). Faces matrix **F** contains all row three vertex index that compose a single triangle face. It is $m \times 3$ in dimension, where m is the number of faces in TIN model.

$$\underset{m,3}{\mathbf{F}} = \begin{bmatrix} v_1 & v_2 & v_3 \\ v_2 & v_3 & v_7 \\ \vdots & \vdots & \vdots \\ v_{n-2} & v_n & v_{n-1} \end{bmatrix} \tag{3}$$

The most important matrix is the index matrix **I**. In this matrix all rows correspond to the vertex point and in columns there are all faces where this vertex appears. So for example if vertex 1 appears in faces 1, 7 and 8 (these are faces index linked by **F** matrix), the first row of **I** matrix will be 1, 7, 8. **I** matrix have $n \times n_{\in \max}$ dimension, where n is the number of points in TIN model. $n_{\max}$ is the maximum number of faces where *V* point appears. This number is research in all TIN model at the begin of **I** matrix construction.

$$\underset{n,n_{\max}}{\mathbf{I}} = \begin{bmatrix} f_1 & f_2 & f_3 & f_4 & f_5 \\ f_2 & f_4 & f_7 & 0 & 0 \\ f_8 & 0 & 0 & 0 & 0 \\ \vdots & \vdots & \vdots & \vdots & \vdots \end{bmatrix} \tag{4}$$

The algorithm was tested on the part of TIN model including 243 points and 414 faces. The justifications for this choice is a better control of optimization process and quick results without long elaboration time. In the test the 5 mm value of $d_{\max}$ was assigned.

In the next step the optimization was made on the niche which is only a small part of structure. The model contained 9019 points and 17 909 faces. Despite relatively small quantity of points, the algorithm needed 15 hours to complete operations. So long operation time proves that the algorithm was not optimized for fast work. After the optimization the TIN included 6051 points and 11 959 faces. It means that in the process of optimization 2968 points and 5950 faces have been deleted. This was a good result. Although some problems in output have been noticed, this causes little discontinuity in TIN model. This problem is caused by the simplicity of the algorithm. For the shape extraction this little problem will not have big importance.

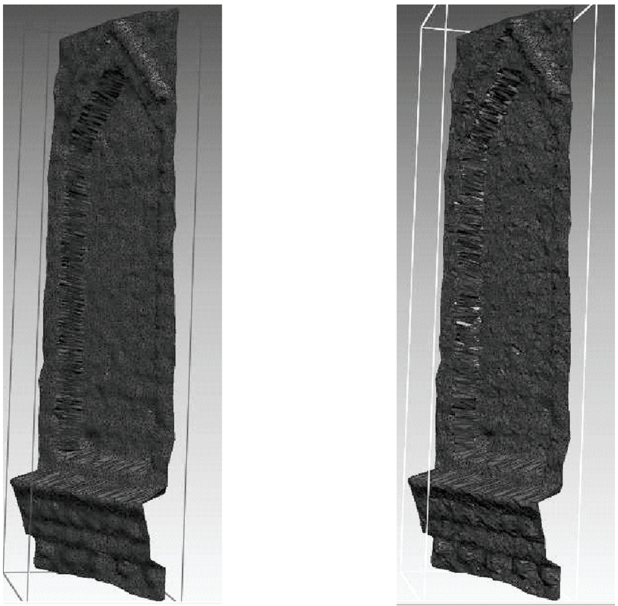


Fig. 11. On the left – view of input TIN (9019 points and 17 909 faces).
On the right – view of output TIN (6051 points and 11 959 faces)
Rys. 11. Po lewej: siatka TIN z 9019 punktami i 17 909 powierzchniami elementarnymi,
po prawej: siatka TIN z 6051 punktami i 11 959 powierzchniami elementarnymi

4. Shape extraction

Approach to shape extraction was made thanks to simple geometrical characteristics. The extraction work started from one observation. Very definite shape, like wall corners, are determined by decisive slants between planes in space. So where there is a wall corner, in the TIN model it is expected that triangles will have a rapid position change in space. In this way if the angle between two adjacent triangles normal vectors is defined, it will be possible to use this principle. Concluding, the rule is

$$\phi > \phi_{max} \tag{5}$$

where:

ϕ – angle between adjacent triangle normal vectors,

ϕ_{max} – reference value of angle.

Where the condition (5) was fulfilled the application indicates triangle borders thus we obtain a form of shape extraction. After some tests it was found that angle ϕ can not be of high value. For this procedure ϕ angle of 30° was used. On the basis of analysis the significant impact of noises has been found. That is why it was necessary to adopt other parameter to highlight shapes.

The second parameter used in shape extraction is area, specifically controlling the triangle area before the border extraction.

The additional control parameter is

$$SF > SF\ min \tag{6}$$

where:

SF – area of the triangle under consideration,

SF min – minimum area value define by the user.

A triangle with a very small area most probably represents a noise data for this procedure. If the application works with two parameters, we obtain a result with less noise.

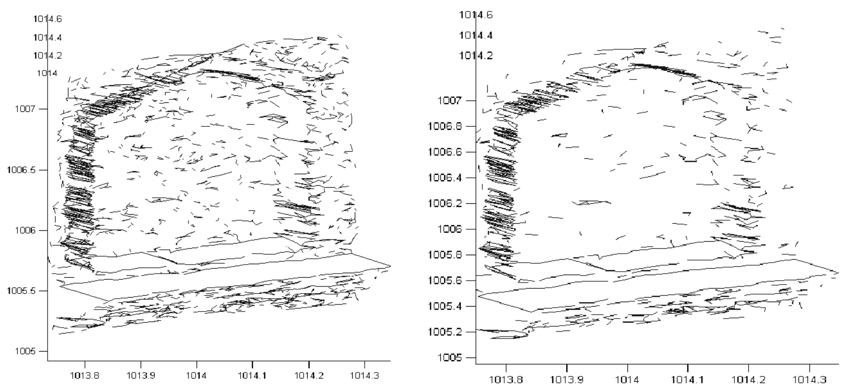


Fig. 12. On the left – result of shape extraction only with ϕ parameter, on the right – result of shape extraction using two parameters

Rys. 12. Z lewej: wyniki opracowania dla parametru ϕ, z prawej wyniki dla dwóch parametrów ϕ i SF

Analysis of the results allows to notice that if TIN model is of good quality the application extracted the shapes. Shape extraction is not completed in the places where the model is not correct, e.g. in niche borders.

The completion of the work was possibile thanks to cooperation and technical help given by Politecnico di Torino. The author expresses his great gratitude to prof. dr Ambrogio Manzino the head of Department of Land Engineering, Environment and Geotechnologies.

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