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MODELING OF QUASISYMMETRIC RING ELEMENTS OF THE CHURCH USING DATA OF GROUND LASER SCANNING

The aim of this work is to develop an algorithm for mathematical three-dimensional modeling of a typical roof of a Ukrainian church based on ground-based laser scanning and to find ways to optimize the model depending on the input data set. Method. The accuracy of the simulation depends on the laser scan data. The number of points obtained and their accuracy will affect the final result – 3D model of the roof. Given the typical design of the church roof in the shape of a cone, you can apply the standard mathematical algorithm for modeling part of the buildings of a typical church. Result The proposed algorithm was developed in the MathCad software environment. 3D scanning materials of the Ukrainian typical church were used to develop the mathematical algorithm. The algorithm analyzes the location of the scanning points of the church roof and performs its averaging. As a result of the algorithm, erroneous measurements were rejected and a model of the part of the roof was obtained, which forms the optimal geometry of the structure. Scientific novelty and practical significance. The proposed mathematical algorithm allows to automate some modeling processes of a typical Ukrainian church for design decisions. This method of modeling can be used for similar structures of other buildings.

Key words: 3D scanning, 3D modeling, automatic modeling algorithm, point cloud, surface construction

Introduction

The result of 3d scanning is a cloud of points that can be used in different ways for different purposes. Typically, the point cloud is the source of input for 3D modeling. The built model is used for analysis, design, etc.

In the practical work of scanning old wooden churches, we encountered the problem of analyzing the roof of the church at high altitudes.

Ground laser scanning data can be used to carry out design work to determine the area and shape of the roof. But given the height of the building and the material of the church roof, the scan data are of insufficient quality. Large measurement errors give large distortions, and therefore modeling can be difficult. Also, the roof of the Ukrainian church cannot be described by a simple geometric figure.

To find the best solutions, the available literature on this topic was analyzed.

In the works [Pang et al., 2015, Patil, et al., 2017] described effective methods of automatic modeling of typical industrial structures – pipes and taps. With standardized sizes and types of piping elements, you can quickly get a spatial model of the object. But this method of modeling is narrow-minded and cannot be used to model other objects.The method of automatic modeling of low-detail buildings is proposed in [Budroni, Boehm, 2010]. The author proposes to segment the cloud of points to determine the parameters of the model. This method of modeling can not be used for accurate reproduction of individual elements of buildings, and its use is appropriate for rapid reproduction of the infrastructure of settlements. A similar study is presented in [Ochmann, et al., 2019], the basis of which is the modeling of flat objects (walls, floors). Research in the field of modeling according to laser scanning data in the field of industry was also performed in [Krysko, 2014]. This paper presents in detail the work of the proposed algorithm, but does not provide a practical simulation result. [Pepe, M., et.al., 2020] conducts practical work on the collection of spatial data by photogrammetric method. Using a cloud of points, the authors perform 3D modeling of buildings with standard software in manual mode. In automatic mode, the construction of the surface is carried out according to existing measurements.

The study of ground-based laser scanning in architecture has been carried out in many works over a long period of time. [Schultz and others. 2016] describes the general principles of scanning architectural monuments and processing the obtained data. [Scopigno et al., 2011] describes the practical results of modeling various cultural heritage sites and describes some features of scanning specific sites. The technology of information modeling and its features are described in [Talapov, 2015] and [Rocha et al., 2020]. But in none of the methods considered by the author of the methods of automation of modeling processes of specific structural elements are found.

The study of the algorithm for modeling flat ring objects was conducted in [Vus, Maevsky, 2015]. The proposed method allows you to accurately describe the shape of wooden logs in cross-sections. But the proposed method describes the shape of the object only on the plane. The full cycle of scanning data processing for modeling interior elements is described in [Poux, et al., 2018]. In addition to the proposed algorithm, the simulation results are presented. However, the main condition for ensuring the implementation of this method is high-quality laser scanning data, which is easy to achieve when scanning the interior of buildings, but difficult to measure distant objects.When modeling the surface, you can also use geometric shapes that fit into the cloud of points. For example, to analyze the deviation of the pipe, it is convenient to build a cylinder of a certain size [Malitsky, 2017] (Fig. 1).

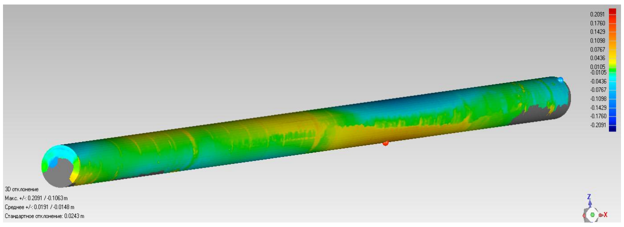


Fig. 1. Display deviations of the Cad-model of the cylinder from the position of the existing pipe [Malitskyi 2017]

This method is worth considering if the scanned object can be described by a set of simple three-dimensional shapes.

In the practical work of scanning old wooden churches, we encountered the problem of analyzing the roof of the church at high altitudes. But the use of this method with the wrong shape will give a bad result.

Method

Ground-based laser scanning is used to collect data for modeling. The church is scanned from various scanning stations, which reproduces the building in the form of a cloud of points. The roof material of the building is of great importance when scanning. Depending on it, the scan data may contain significant measurement errors or may not be present at all. The number of laser scanning points obtained and their accuracy will affect the final result – 3D model of the roof. Depending on typical form of the roof of the church, you can use a respective algorithm for modeling part of the buildings.

The primary task when processing scan points is to filter the input data that will be used for modeling. The representation of the position of the scan point can be described by two variables – the change in the height of the section of the object and the radius vector to the surface from the axis of symmetry of the object.

The radius-vector is a function that depends on the value of azimuth A and the height of the section f (Fig. 2):

$$r = f\left(A; f\right). \qquad (1)$$

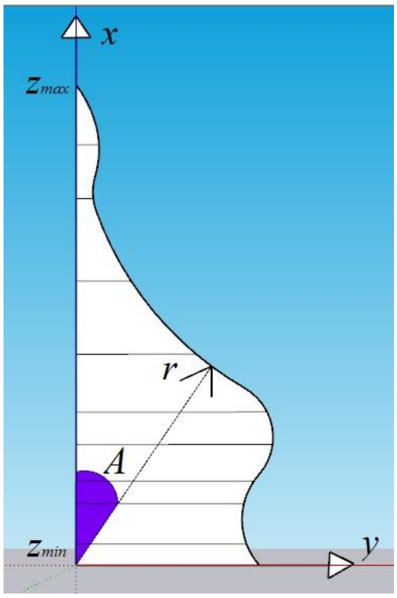


Fig. 2. Scheme of construction of sections for creating an average model

In the Cartesian coordinate system, the z axis is the variable h, the x axis is the projection of the vector r on the x axis, which is determined by the following expression:

$$x = ax_0 \cos A + \sum_{i=1}^{n}(ax_{ci} \cos f_i \cos A +$$
$$+ax_{si} \sin f_i \cos A)$$

$$y = ay_0 \sin A + \sum_{i=1}^{n} (ay_{ci} \cos f_i \sin A + +ay_{si} \sin f_i \sin A), \quad (2)$$

ax_0, ax_{ci}, ax_{si}, ay_0, ay_{ci}, ay_{si}, – Fourier series coefficients
n – number of harmonics of the Fourier series;
i – iterative harmony, $1 \le i \le n$.
f_i – change the height of the section in the angular measure.

We can change the section height into an angular dimension using the following expression:

$$f_i = h_i \frac{2\pi}{(h_{max} - h_{min})}, \quad (3)$$

where: h_{max}, h_{min} – the maximum and minimum heights of the object's points, h_i – the height of the i-th point.

Fourier series coefficients ax_0, ax_{ci}, ax_{si}, ay_0, ay_{ci}, ay_{si} – are determined by the method of least squares from the solution of 2 *i numbers of equations. That is, each point determined by scanning forms two equations (2).

To ensure the optimal simulation result, the proposed algorithm uses different levels of surface complexity. To do this, we use a different number of coefficients i. As the number of these harmonics increases, the model becomes more detailed and takes into account more surface measurements.

Therefore, the next step is to build an average profile using the Gaussian smoothing function.

To build a profile, set the number of vertical and horizontal sections.

The final step in building a model is to use a smoothed profile to solve a Fourier series

Results

To develop a modeling algorithm, laser scanning materials of a wooden church in the village of Sushno, Radekhiv district, Lviv region was used (Fig. 3). The scanning was performed with a Faro Focus 3D 120 scanner. According to the technical characteristics of the 3D scanner, the shooting accuracy is +/-2 mm/25 m with a reflection coefficient of the laser beam from the surface of 90 %. Roof measurements were performed from 6 scanning stations with different settings of measurement speed and resolution. Measurements from all scan stations are registration in Faro Scene 6.2 software using spheres. The accuracy of scan orientation is 0.7 cm. The average distance from the location of the scanner to the farthest element of the church is 24 m.

Fig. 3. Cloud points of the scanned church Sushno village Lviv region

Not all laser scanning points were used to process the scan data, but only the ones that reproduce the roof of the church. Studying automatic modeling method, about 13.000 scanning points were used, which the model was built on.

To recreate the roof of the church, the cloud of points was divided into 2 parts. The lower part of the roof point cloud contains insufficient measurements due to limited visibility of the object. This part of the cloud of points was processed manually by entering polygons (Fig. 4). It was taken into account that the roof in its structure consists of 8 faces.

The upper part of the roof of the church is round, without faces in its structure. The results of scanning this part of the building contain large measurement errors. Point filtering was used to further process this data. In our case, the maximum deviation of the position of the point was 10 cm. In our case, the maximum deviation of the position of the point relative to the x and y axes was set to 10 cm. This dropped about 1 % of the points from the overall list of all dimensions.

The processing of the point cloud is performed automatically using algorithm proposed below.

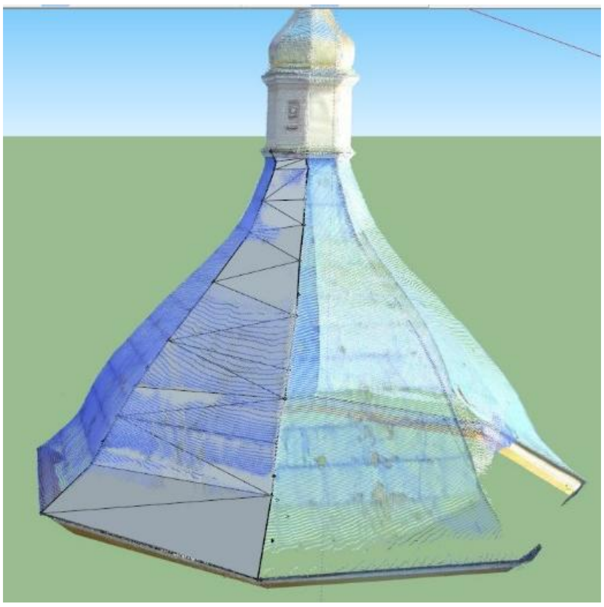
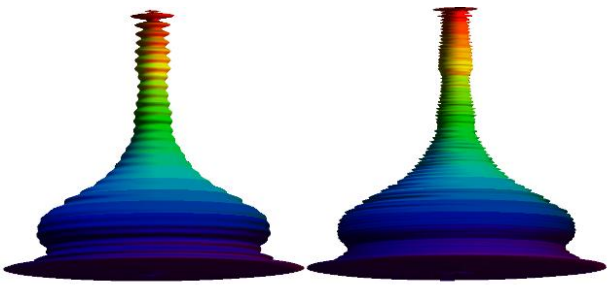


Fig. 4. The results of manual modeling of the lower part of the roof of the church

Analyzing the upper round part of the roof, we come to conclusion that there are certain shifts in symmetry. Therefore, different roof sections will differ. To model the roof, all scan points should be analyzed, filtered, smoothed and accurately evaluated.



a b

Fig. 5. Model of the roof of the church at a – i=30; b – i=80

To determine the optimal squaring of the points, the average error of the model was created. Using the value of i = 40 we obtain the accuracy of the model 3.2 cm. As the value of this coefficient increases, the accuracy of the model hardly changes. We also tried to change the filtering threshold of the scan points. But the change in point filtering did not give tangible results.

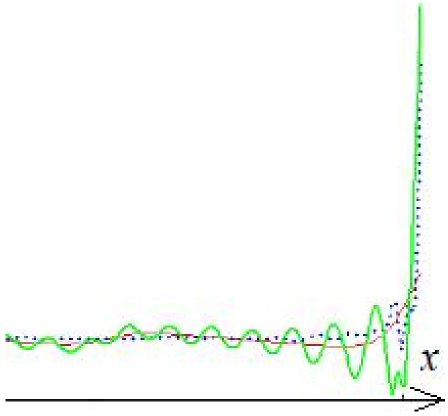
The detaility of construction of the average profile depends on their quantity. In our case, we use the smoothing factor n=100.

Fig. 6 shows the part of the model with the largest number of erroneous measurements:

– laser scan measurement the upper part of the profile (blue dots);

– the upper part of the profile of the constructed model (green thickened line) at i=30 and i=80;

– the upper part of the profile of the smoothed model according to the Gaussian filter (red thin line).



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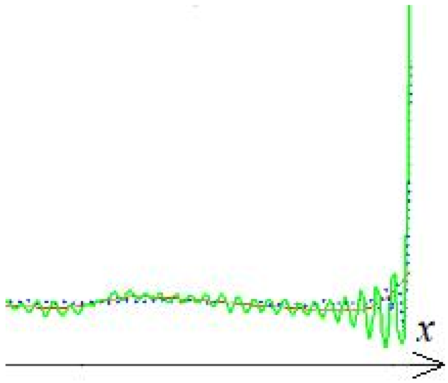
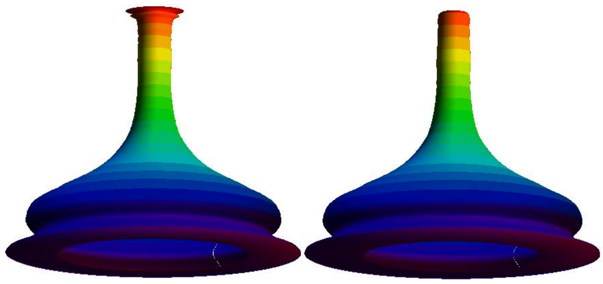


b

Fig. 6. Vertical sections of models using a smoothing filter

Fig. 7 shows the obtained model of the church roof with the initial coefficients i = 30 and i = 80 and the smoothing coefficient n = 100.



a b

Fig. 7. Smoothed model at n = 100 models with the number of harmonics a – i=30; b– i=80

The use of a simple mathematical expression allowed to transform the laser scanning data into an accurate quasi-symmetric model, taking into account the existing local deformations and filtering gross errors in measurements.

Conclusion

A quasi-symmetric ring shape modeling algorithm has been proposed and implemented in MathCad software, which describes the spatial surface in two variables – the azimuth of a point relative to the axis of symmetry of the object and the height of the section. After processing the scanning points of the laser scan, and despite gross errors in measurements, an averaged quasi-symmetric model of the church roof was created by an automated method. The root mean square error of the model is 3.2 cm. This result is due to the accuracy of the surface scan and its shape. We can say that the claimed accuracy of ground-based laser scanning 2 mm / 25 m at the reflection coefficient of the surface was not achieved. Scanning data filtering was applied, which could improve the accuracy of the model by 7 mm. The optimal number of harmonics to create an accurate model and the optimal smoothing index to simplify the model are determined.

The constructed model can be considered as one of the stages of digitizing the point cloud. The proposed method is optimized for creating models in order to monitor and find deviations from the base model. Further research will involve comparing models developed by other known methods using existing software.

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Андрій МАЛІЦЬКИЙ

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МОДЕЛЮВАННЯ КВАЗІСИМЕТРИЧНИХ КІЛЬЦЕВИХ ЕЛЕМЕНТІВ ЦЕРКВИ ЗА ДАНИМИ НАЗЕМНОГО ЛАЗЕРНОГО СКАНУВАННЯ

Мета цієї роботи – розробити алгоритм математичного тривимірного моделювання типового даху української церкви за даними наземного лазерного сканування та знайти шляхи оптимізації моделі в залежно від набору вхідних даних. Методика. Точність моделювання залежить від даних лазерного сканування. Кількість отриманих точок та їхні точність будуть впливати на кінцевий результат – 3D-модель даху. Враховуючи типову конструкцію даху церкви у формі конусу, можна застосувати стандартний математичний алгоритм моделювання частини споруд типової церкви. Результати. Запропонований алгоритм розроблений у програмному середовищі MathCad. Для розроблення математичного алгоритму використано матеріали 3D-сканування української типової церкви. Алгоритм аналізує розташування точок сканування даху церкви та виконує його усереднення. В результаті роботи алгоритму відбраковано помилкові виміри та отримано модель частини даху, яка утворює оптимальну геометрію споруди. Наукова новизна та практична значущість. Запропонований математичний алгоритм дозволяє автоматизувати деякі процеси моделювання типової української церкви для проектних рішень. Такий спосіб моделювання може застосовуватися для подібних конструкцій інших будівель.

Ключові слова: 3D-сканування, 3D-моделювання, алгоритм автоматичного моделювання, хмара точок, побудова поверхні.

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