Comparison of 3D Photogrammetric Modeling Methods

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***Abstract* – Close range photogrammetry is a commonly used process in the 3D modeling of existing structures. Two modeling methods have been developed for photogrammetric processing. One of them is the photogrammetric assisted CAD editing. The other one is the application of TIN surface based on dense point cloud. I examined the two methods by the 3D modeling of a structure with non-regular surface. My paper studies and compares the two modeling methods and lists advantages and disadvantages, as well as the expected accuracy.**

***Keywords* – close range photogrammetry, digital photogrammetry, 3D modeling**

I. INTRODUCTION

3D modeling of structures is a widespread engineering process nowadays. The spatial geometric model of structures may be used for visualization, archiving, but also as a design model. One method of the 3D modeling of structures is the photogrammetry-based modeling. In this case the spatial location of points of the model can be extracted from images, taken about the object. The result of this procedure is a surface model. The main advantage of photogrammetric 3D modeling is its low cost. This procedure does not require expensive and complex instrument, data acquisition can be done with a simple digital camera.

II. 3D MODELING

The model is defined as a data system representing the physical object. In computer modeling a digital representation is performed by describing object in mathematical way. The resulted geometric model can be displayed or modified with IT tools. The modelled object can be imagined, or real and existing model. In digital modeling we try to describe complex object with a simple, easy-to-use data structure.

The creation of the model is possible using geometrical elements that can be produced in mathematical form. For modeling characteristic point of the object, curves and surfaces, and in certain cases volume elements are used. Depending on the type of geometric elements used for model creation, the 3D model may be a wireframe model, a surface model or a volume model. (See Fig. 1.)

Another option is the point cloud, which is suitable for spatial modeling. But using point cloud alone for modeling has a limitation in the engineering.

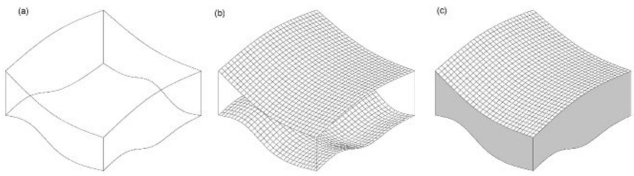

Figure 1. 3D model types: wireframe model (a), surface model (b), solid model (c)

A. *Wireframe model*

The wireframe model was the first 3D modeling technology. It is the simplest method where little data needs to be stored and the data structure is simple. With the wireframe model the edges of the physical object can be represented. The wireframe model consists of points (or vertex) and curves connecting the points. Despite its simplicity, the wireframe model is less frequently used because of its disadvantages. It cannot represent surface, so that the texture of the physical object cannot be displayed. Furthermore, the visibility of edges cannot be solved by using this method.

B. *Surface model*

Surface model or shell model can be considered as a further development of the wireframe model. The principle of this technology is the fact that physical objects are bounded by surfaces, either by regular or irregular surfaces. Surface is bounded by curves, and curve is defined by points. Triangular irregular network is often used to approximate irregular surface, where the triangle of the network itself is a regular surface.

The surface model is the most commonly used method in the photogrammetry-based modeling. Texture and shading can be defined on the surface model, and the result will be a realistic-looking model. The texture of model is extracted from photos. Because of its realistic-looking properties, the surface model is popular in visualization and animation.

C. Solid model

The solid model represents volume. It provides realistic modeling, but the process requires high computing power. There is a greater role of solid modeling, where the material nature of the physical object is important. Accordingly, it is mainly used in product development and production, in CAD and CAM systems. During manufacture additive or subtractive processing is performed, resulting in the modification of volume characteristic of the object. Solid modeling is performed by using primitive volume bodies.

For modeling of structures and buildings, the solid body is less interesting. At the same time the outer geometric dimensions and other attributes (such as wall thickness, surface quality, texture) are more important. However, in some cases solid model can be useful in geoinformatics. The recently appeared voxel (volume pixel) technics is becoming more and more popular in the 3D modeling where the volume model is built from small elementary volume blocks.

III. Modeling with photogrammetric data extraction

Creating a spatial model requires measuring points of the modeled physical object. Then these points (primarily vertexes, intersections or characteristic patterns) can be represented in the model coordinate system.

In modeling, we can also create fictional model that does not exist. These models are used in design and can be defined by calculation or by defining in editor programs.

In the case of modeling of an existing physical object, the first task is to perform data extraction by measuring the object in a fixed coordinate system (that may be local or geodetic coordinate system). There are several ways to gain data. Using laser scanner (LIDAR) is widespread and commonly used nowadays. Furthermore, a conventional measurement method can be used, too like measuring tape or total station.

In addition to the above-mentioned data collecting methods, photogrammetric measurement and processing is a fast, efficient and cost-effective way to obtain spatial data. It is an advantageous feature of the photogrammetry that texture of the surface can be extracted easily from photos, while the laser scanner does not provide a coherent texture.

During the photogrammetric survey of buildings and structures the so-called close-range photogrammetry is used, when the collection of photography is performed from lesser distance than the traditional aerial photogrammetry survey is done (usually closer than approximately 100 m).

When a photo is taken, a central projection has been performed to the image plane. The spatial data will then be lost and as a result we will get a two-dimensional flat image (or projection) of the physical object. In the photogrammetry process the spatial position of the image will be restored. (See Fig. 2.) If the spatial position of the image pair from different view is known, the coordinate of the common point marked on the images can be calculated, resulting in the point of the model.

During the photogrammetry procedure for 3D modeling, the classical photogrammetry workflow is performed. Main steps of this workflow are the following:

Planning of acquisition. Before performing image capture, a plan is necessary to specify the number and overlap of photos required for photogrammetric process. It is especially important if an UAV is used.

Capture process. The number of photos depends on the method of modeling. For recording using digital cameras is widespread in photogrammetric survey. It can be performed from the ground, but using UAV is becoming more typical.

Internal orientation. A two-dimensional coordinate system is assigned to the image plane. This ensures that the points of projected object can be identified in a plane coordinate system.

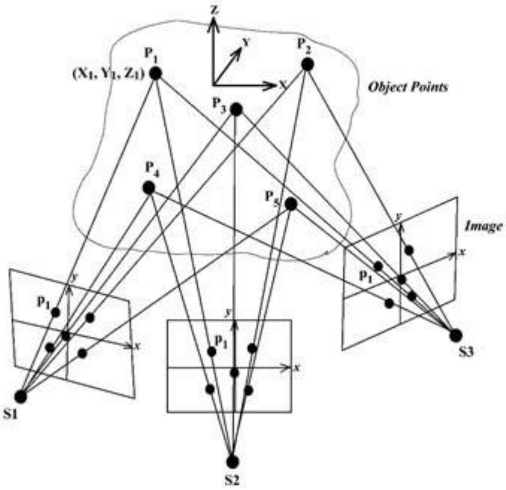

Figure 2. Schematic view of photogrammetric process. There are three images from different view with projection center (S). Object points (P) are projected to the image plane

External orientation. It means the definition of location of the image in the space, namely coordinates of the projection center and angle of rotation of image plane. This is solved by numerical solution of non-linear equation system.

Calculation of points of the model. If spatial locations (coordinates of projection center, angles of rotation) of images are known, using stereo pairs the spatial location of associated pixels on image pair can be calculated. As a result of this processing, every specific points of the model we need can be defined. Using these points in the model space, a required model can be built with various modeling methods.

IV. Model construction

For photogrammetric surface modeling, two typical procedures have been performed. The oldest is the manual or semi-automatic editing and drawing using CAD style application with photogrammetric assistance. In such a system the photogrammetric module provides data for editing and drawing. Using this manual method (or with some semi-automatic assistance) characteristic point of model can be edited by intersecting lines of sight. A wireframe model can be fitted to these points and then surfaces are fitted on the frame.

Development of computing technology made the automatization of digital photogrammetric process possible. Image matching procedures allow to automatically recognize matching points in stereo photo-pairs, and automatic generate dense point cloud. A triangulated irregular network can be placed on points of the dens point cloud. The TIN mesh makes possible to approximate the complex surface of the object, while the TIN mesh consists of regular triangular surfaces.

Because of the increase of computing power and the spread of convenient, easy-to-use automated photogrammetric software, the generation of dense point cloud and photorealistic surface model is simple and efficient. For this reason, the photogrammetry modeling technology based on point cloud became the dominant one nowadays, while manual modeling with regular surfaces has lost its importance.

V. Modeling example

In this paper the characteristics of the two above mentioned modeling technologies are presented through a specific example.

As a modelled structure, the Gold Bull monument in Székesfehérvár has been surveyed for photogrammetric processing and modeling. This structure bounded by regular and irregular surfaces, it has complex surface, so that it is capable of testing strengths and weaknesses of these two modeling methods.

For manual modeling the PhotoModeler software was used, which is essentially a photogrammetry assisted CAD editing program.

The dense point cloud-based modeling was carried out with the PhotoScan (lately MetaShape) software that allows automatic image matching, orientation, and generation of point cloud and mesh. However, it is a software with higher automatization, a sophisticated setup is possible.

For taking photos about the structure a Sony Alpha A350 digital camera was used that was previously calibrated. A total of 161 photos were taken. About two dozen of photos were used for modeling in PhotoModeler, and all of them were used in PhotoScan.

Ground control points (GCP) were also surveyed for transformation model into the World coordinate system and for analytics of accuracy of the model [5].

VI. Comparison of methods

The two software that were used for 3D modeling, make two different modeling concepts.

A. PhotoModeler

PhotoModeler is essentially a photogrammetry assisted CAD editing tool with a software module, that is capable of gaining spatial data for 3D wireframe and surface modeling. This software is a quick and efficient tool for manual editing and modeling of simple, regular shapes. This model is economical, storing of model data requires less memory, and rendering and displaying are quick. This procedure requires fewer photographs. If the projection rays intersect at right angle or close to it, this method has good accuracy.

However, using this method for modeling of objects that have complex and irregular surfaces is not ideal, the process is time consuming and has difficulties. Because of the irregular surface the errors of model will be larger than expected. For this reason, and because of the widespread using of UAVs, PhotoModeler has been developed and a point cloud based automatic photogrammetric module (PhotoModeler Scanner) has been added to the software. Using PhotoModeler Scanner could have been more efficient in recent case, but the manual editing method was used with PhotoModeler to evaluate the two different modeling methods and to compare these methods by empirical means.

There were significant errors resulted by manual editing in the PhotoModeler software. This is due to the fact that some parts of the structure are not visible on photographs, and some surfaces are visible only from very small angle. Therefore, in the editing of points, the tie point selection was characterized by uncertainty.

B. PhotoScan

PhotoScan provides highly automated photogrammetric processing. It produces TIN surface model based on point cloud. It can be used for modeling of structures with complex, non-regular surfaces. Using today's computing power, processing time is already acceptable.

Figure 3. The point cloud model generated by automatic image matching procedure (PhotoSacn)

The need of many photographs with high overlap can be considered a disadvantage. For this reason, the photogrammetric surveying requires more time. In some cases the software tends to calculate wrong points. However, the software is highly automated, but this does not mean that there is no need for manual intervention, the point cloud should be cleaned of wrong points.

The detection of points may be defective in certain places, especially where projection rays intersect in small angle. In this case the photogrammetric procedure does not recognize points belonging to the model that will have holes on the surface. (See Fig. 4.)

Figure 4. A fragment of the model with discontinuities of the surface

The data representation of point cloud based on TIN surface mode needs big storage capacity. The point cloud consists of points detected randomly as a result of the automated image matching.

Figure 5. Orthogonal view of surface model generated by PhotoModeler

Both methods indicate that taking photographs of appropriate quality is important. The improved light conditions increase the accuracy and visual appearance of the model. Instead of direct sunshine, it is better to take photos in diffused light. For modeling larger object, it is advisable to use aerial survey by taking photos from an UAV.

VII. Accuracy analysis

During the modeling task presented in this paper an accuracy test was performed, too. For this test control points were used, which were surveyed by geodetic method. Six of the surveyed points were used as ground control point for coordinate transformation to the geodetic coordinate system.

The remaining points were used to calculate errors. Using these points, the difference between coordinates of control points in the models and coordinates of the real object were calculated. From these values root-mean-square error (RMS error) were calculated in X, Y and Z direction, and in the XY plane.

RMS error was calculated with the following formulas:

$$M_x = \sqrt{\frac{\sum_{i=1}^{n} \Delta X_i^2}{n-1}}$$

$$M_y = \sqrt{\frac{\sum_{i=1}^{n} \Delta Y_i^2}{n-1}}$$

$$M_z = \sqrt{\frac{\sum_{i=1}^{n} \Delta Z_i^2}{n-1}}$$

$$M_{xy} = \sqrt{\frac{{M_x}^2 + {M_y}^2}{2}}$$

where M indicates the RMS error, Δx, Δy and Δz indicate errors of model points.

In both cases the RMS error is around the expected centimeter value, which is a tolerable and typical error in modeling of structures by performing close range photogrammetry process.

TABLE I.
RMS errors of the two model

	RSM error [m]	
	PhotoModeler	PhotoScan
M_x	0.0218	0.0074
M_y	0.0277	0.0065
M_z	0.0182	0.0129
M_{xy}	0.0249	0.0070

In the Table 1. RMS errors can be seen resulted by modeling with PhotoModeler and PhotoScan software. PhotoModeler's RMS error was slightly higher (2 cm) than it was expected. This is due to the complexity of the surface of object, resulting bigger errors at some points. These errors affected the accuracy of the model as a whole. It also justifies the assumption, that manual editing complex surface is less appropriate, while using TIN mesh provides more accurate model.

VIII. EXTRACTING GEOMETRY FROM POINT CLOUD

Using point cloud in the photogrammetric processing is widespread because this method can be well automated. The process is quick, and the model as a result is accurate. However, it is less advantageous in the practice of engineering. The point cloud is not structured, there is no topology in the cloud and the TIN model provides only representation of the surface. It is no easy to handle point cloud model in the engineering design systems or GIS applications. For these applications the regular model is more practical.

To use model in engineering systems, shapes should be extracted from the point cloud. This process is mainly manual or semi-automatic nowadays. Object detection and identification require human spatial ability. However, automation of the spatial object detection is in progress already, machine learning and artificial intelligence have opened new opportunities in this area of technology.

The question of generalization and level of details should also be mentioned. In many cases, the detailed model of object or structure is not needed. For example, minor roughness of a plain wall in not an important information that should be presented on the model. Generalized model meets the requirements in many cases.

Typical example of application of generalized model is the Building Information Model (BIM), where storing data about small details of the real object are not required. Main geometry dimensions can be extracted from photogrammetry and the generalized BIM model consisting of regular surfaces can be produced from point cloud [1]. (See Fig. 6.)

Engineering design software offers a number of solutions to perform point cloud-to-BIM task. One of the widespread applications with point cloud data to BIM capabilities is the Autodesk Revit, that is capable to generate model from point cloud by using manual, semi-automatic and automatic ways.

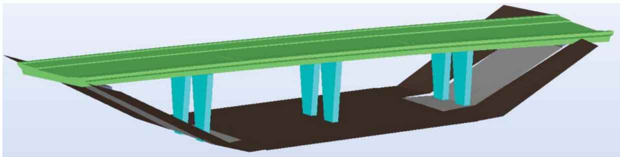

Figure 6. BIM model extracted from point cloud. Source: BIM Handbook, p. 196.

IX. CONCLUSIONS

Using of point cloud in photogrammetric processing is widespread because of its efficiency, but regular CAD models can be better used in engineering tasks. However, manual modeling based on photogrammetric data extraction is simple and fast in case of modeling of regular shapes, so that this method also has the right to exist today. For irregular, complex object the manual editing method is difficult and time-consuming.

Spatial modeling based on close range photogrammetry ensures cm-level accuracy, which is sufficient in geodetic and engineering practice.

Storing of the point cloud data is a resource consuming method, so that it is a preferred way to extract regular CAD model from the point cloud for use it in engineering systems. The extraction of regular geometric model performed by manual, semi-automatic and less frequently automatic method.

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