Application of the Triangulated Irregular Network (TIN) Method in the Creation of Models of Historical Buildings

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Abstract. Renovation or modernization of a historical building involves creating its model. An accurate 3D representation of a building can be used e.g. to analyse the possibilities of renovating or recovering its damaged elements. This paper discusses examples of how helpful 3D laser scanning can be in creating models of historical buildings. This technology is of particular importance when it comes to representing decorative architectural details. To create a 3D image of a building using reverse engineering one must first gather on-site data by means of terrestrial laser scanning in the form of a point cloud. This paper describes the process of creating a model of a historical building by means of the TIN method using Leica's Cyclone programme. The on-site measurements were taken using a ScanStation C10 scanner, also by Leica.

1. Introduction

The most popular measuring techniques include the so-called photogrammetric methods (two and multi-image, using structural light, shadows, etc.) and laser scanning. They are used to create point, skeleton and surface models, rarely represented by three-dimensional elements, i.e. the so-called voxels [6]. Terrestrial Laser Scanning (TLS) applies a beam of light to create a 3D image of the measured object. This non-invasive method is used to represent the surface of land and many other objects in the form of a point cloud. Each of its elements is described by means of X, Y, Z coordinates and the light beam intensity as an additional coordinate I. This data can be processed into maps, terrain models and 3D models of different objects [3]. Terrestrial laser scanning has numerous applications. It is used in taking measurements of large, vast objects, otherwise difficult to measure manually, such as bridges and overpasses [1] or buildings with a complex structure, e.g. conservation buildings. Sometimes laser scanning allows for taking detailed measurements of such objects. This method is also useful in analysing the movement and deformation of coal or rock layers in mines. Scanning has a lot of applications in construction and architecture. For example, it allows for conducting accurate surveys not only of entire objects, but also of their structural or decorative features. By means of reverse engineering resulting from this technology one can examine the technical condition of a building or create a representation of its decorative features. This non-invasive and accurate method is particularly useful in creating documentation and models of historical buildings [4]. Laser scanning allows for creating a detailed representation of objects of complex shapes. This is particularly important in the case of historical buildings, most of which are rich in decorative details, whose accurate modelling depends also on the visualisation method [2,3]. A point cloud created in the
process of laser scanning is used mainly to create point-based (Fig. 1a) and surface models, comprised of triangles whose apexes constitute measuring points. This is the so-called Triangular Irregular Network model (Fig. 1b), which can be obtained automatically. As far as a point cloud is concerned, one can fit the standard geometric shapes into it semi-automatically to arrive at a volumetric model (Fig. 1c). In contrast, skeleton modelling is still far from being sufficiently automated.

The most popular model applied in analyses requiring a very precise object representation is the point-based model (Fig. 1a). It is based on a point cloud created during a field research with no modelling done to it. An object represented only in the form of points is isolated and cleared of redundant data.

TIN is one of many methods of creating point cloud-based 3D models of existing objects. The TIN network is comprised of triangles whose apexes are the neighbouring three points in a point cloud. The final effect depends on the accuracy of the network shape (Fig. 1b).

Volumetric models (Fig. 1c) are less precise and provide a poorer representation of physical objects. In some cases, however, e.g. when the point cloud data is insufficient and precise representation is not required, this method proves effective [5].

![Figure 1. A building façade model: a) point-based, b) TIN-based, c) volumetric](image)

2. Modelling a triangular network based on a point cloud

Conducting surveys of historical buildings is a difficult task. Their complex architecture and rich detail make taking the necessary measurements difficult and time-consuming. It is important to place the measuring stations in such a way as to allow the laser beam to cover an entire object. This condition must be met in order to be able to obtain complete data in the form of a point cloud. At this stage, i.e. at the stage of conducting a field research, one should decide on the precision of the measurements to be taken, as it is this precision that the accuracy and density of the resulting point cloud depends upon. Imprecise and carelessly taken measurements will result in the inability to create a detailed model. This will primarily affect reverse engineering, i.e. the quality of models. This issue is shown in fig. 2 where a point cloud has been modelled by means of the TIN method, and features a surface represented by an irregular network of triangles. The unnatural-looking surfaces result from the lack of input data and do not represent the actual structure of the façade (Fig. 2).

If measurements are not very precise, it means that the distances between particular points in the cloud are big, as a result of which, the programme may have a difficulty generating the right mesh model. Therefore, one should first manually set the network direction and axis beforehand. If the axis is set inaccurately, the programme will wrongly connect the points comprising the network (Fig. 3).
In Cyclon, the algorithm for creating a network of irregular triangles allows for corrections. All points are interconnected and sometimes certain connections are unacceptable. The operator can manually remove redundant connections, as shown on the example of the window, and incorrect connections between the door frames, as well as incorrect connections between the points on the base (Fig. 4).

Figure 2. Decreased density of the TIN network resulting from insufficient data: a) a view of a fragment of the façade, b) a fragment in the form of "LOD - Full Range", c) a fragment in the form of "Wireframe"

Figure 3. Mesh models generated: a) correctly, b) incorrectly
The triangular network can have three forms: "LOD – Full Range," "Wireframe" and "Per – Face Normals" (Fig. 5). The first one smooths out the mesh to the maximum, the second one shows the point-line structure, and the third one shows the sharp edges. Application of these structures allows for calculating the surface of the network to e.g. determine the quantity of materials needed to renovate a façade. The comparative measurements prove that each of these networks provides identical precision and results.

In order to give a model a natural look, a texture is applied. The ScanStation C10 scanner takes digital photographs during measurements. This way, the point cloud can be generated in the form of a point model without colour (Fig. 6a) or with a texture superimposed on it (Fig. 6c). Texturing in Cyclone consists in superimposing a bitmap image onto a spatial object (Fig. 6b), i.e. textures carrying
information about the surface colours and other parameters of an image. This data includes e.g.
information about the lighting model, such as: the colour of the diffused and reflected light,
transparency, the refractive index, etc. In addition, Cyclon allows for representing fragments of images
on a surface of a triangular network by reconstructing the spatial projection. This method consists in
determining the function connecting an image to a model based on adjustment points. However, there
are no visible external or internal orientation elements, while the texture is applied automatically.(Fig.
1b)

Figure 6. Data obtained by means of a scanner in the form of a: a) point model without colour, b)
panoramic bitmap obtained by means of the scanner camera, c) point cloud with a superimposed
texture

3. Summary and conclusions
3D data obtained by means of a laser scanner is highly accurate and, therefore, this method is
becoming increasingly popular in reverse engineering. Compared to the volumetric method, TIN
modelling offers high precision and is very effective in representing the structure of an object's
surface. This is primarily related to the distances between particular points and their number. In
addition, it provides for the possibility of superimposing on the triangular network and the point-based
model a texture based on pictures taken by the scanner and giving it a natural colour.

A triangular network can be applied in the case of objects of more or less complicated shapes.
However, if a very precise image of a model is required, a better solution is to show it as a point-based
model. Irrespective of the method applied, the generated model is generalized, as some details are
invisible. Hence the importance of accuracy and quality of the data obtained in the course of a field
research. It is important to select such parameters as to ensure that the resulting point cloud has the
right density to be used as a basis for representing damaged elements in a virtual space. A digitized
object can be exported to a CNC device software (Computerized Numerical Control), which can create
a very precise, physical copy of a damaged object to replace it.

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