"Environmental Engineering" 10th International Conference
Vilnius Gediminas Technical University
Lithuania, 27–28 April 2017
http://enviro.vgtu.lt

eISSN 2029-7092 / eISBN 978-609-476-044-0
Article ID: enviro.2017.180
DOI: https://doi.org/10.3846/enviro.2017.180

Low Cost Methods Used to Create 3D Models

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Abstract. During the last years the softwares and applications that can produce 3D models using low-cost methods have become very popular. What is more, they can be successfully competitive with the classical methods. The most well-known and applied technology used to create 3D models has been laser scanning so far. However it is still expensive because of the price of the device and software. That is why the universality and accessibility of this method is very limited. Hence, the new low cost methods of obtaining the data needed to generate 3D models appeare on the market and creating 3D models have become much easier and accessible to a wider group of people. Because of their advantages they can be competitive with the laser scanning. One of the methods uses digital photos to create 3D models. Available software allows us to create a model and object geometry. Also very popular in the gaming environment device – Kinect Sensor can be successfully used as a different method to create 3D models.
This article presents basic issues of 3D modelling and application of various devices, which are commonly used in our life and they can be used to generate a 3D model as well. Their results are compared with the model derived from the laser scanning. The acquired results with graphic presentations and possible ways of applications are also presented in this paper.

Keywords: 3D model, sensor Kinect device, laser scanning.

Conference topic: Technologies of geodesy and cadastre.

Introduction

In the recent years the process of digitalization and generating of 3D models have become popular in a wide range of application. In effect, many softwares and applications that can produce 3D models using low-cost methods of measurement have been created. They can be, and over time they certainly will be, a competition for a still expensive classical methods. Laser scanning is commonly known as the classic method of data collection. However, due to the price of the device and software, the popularity and availability of this method is very limited. Therefore the new technologies of obtaining data to create 3D models appeared on the market. Due to their low cost and easy acquisition of the data compared with the scanning technology, they may be a successfully competing solutions. One of these methods can be photogrammetric method, using digital images obtained by amateur digital cameras. Whereas a huge development of computer games has contributed to design devices called sensors which allow players to interact in virtual reality and also give a possibility of generating 3D models.

With these new capabilities creating 3D models have become easier, rapid and hence more accessible to a wider range of people. Therefore, a large number of other softwares not only for professionals but also for ordinary users, who want to explore the secrets of 3D modeling, appeared on the market. This inspired a lot of people, including the authors of this article, to use this device to create 3D models of various objects.

Modeling 3D

The process of creating and modifying three-dimensional objects is called 3D modeling. This process is conducted by using specialized computer programs that provide a wide range of tools necessary to create a 3D model of selected objects in the short time.

We can distinguish three types of three-dimensional models (Sydor 2009):

- wire-frame,
- surface,
- solid.

The first one is the most simplified representations of the 3D objects. All of the elements are shown using only the points and vectors. Due to the limited possibilities of visualizing the further processing is very difficult therefore the usability such models is small. (Sydor 2009).

The second one, the surface models, are created based on the elementary and free surfaces. They are described with more or less complex mathematical expressions. Noteworthy is the fact that the obtained models can be further processed using advanced methods of graphics processing (eg. rendering). (Sydor 2009).

The last of the listed models can be created in two different ways. Using the primitives volume combined with each other the algebraic operations or using pre-defined 2D objects through their movement and rotation.

Nowadays, the application of 3D modeling is very wide. One of them is the architectural inventory which is often link to the archeological inventory (Hejbudzka *et al.* 2014; Mitka 2007). The 3D models help to collect information about the monuments and they are often used to visualize objects. In the archaeological inventory the 3D technology allows us to obtain data with a high accuracy and then we can dimensions very accurate each single element of the object or structure. In addition, their surfaces or volumes can be calculated without any problems. One of the further step after the 3 D modeling can be forming a replica of the object that in turn can be used for the implementation of silicone molds or plaster casts. The advantage of 3D models is also the possibility of visualization the archaeological sites and presenting them not only in the museum but also in virtual reality. The 3D models excellent presents the form of "virtual museums". Other applications of this technology include industrial inventory, medicine, the generation of digital terrain model, calculation of the land mass, architecture, entertainment and much more.

An additional advantage of the 3D model is its readability, which can be used among other things for publicity purposes. We can use the schematic display which is available in the software. To present the object we can use the usual cloud of points. However to show the more complex shapes or calculated needed information about the object- the wireframe model or smoothed and shaded surface model should be applied.

The process of creating point clouds using terrestrial laser scanning

Terrestrial laser scanner emits in a quick way pulsed or phase laser beam, mainly distribution electromagnetic wave of visible or near-infrared spectrum (Fig. 1).

Fig. 1. Terrestrial laser scanner with the pulsed laser beam
source: www.youtube.com/watch?v=_NxCfYkPYBI

During the scanning the mirror (or mirrors depend on scanner model) rapidly swirling or oscillating. Additionally one of the mirror rotate around a vertical axis of the instrument changes the direction of the laser beam and in that way it is possible to collect the data of the object. The result of such a procedure is called "sweep" or spot coverage of the scanned object (Fig. 2).

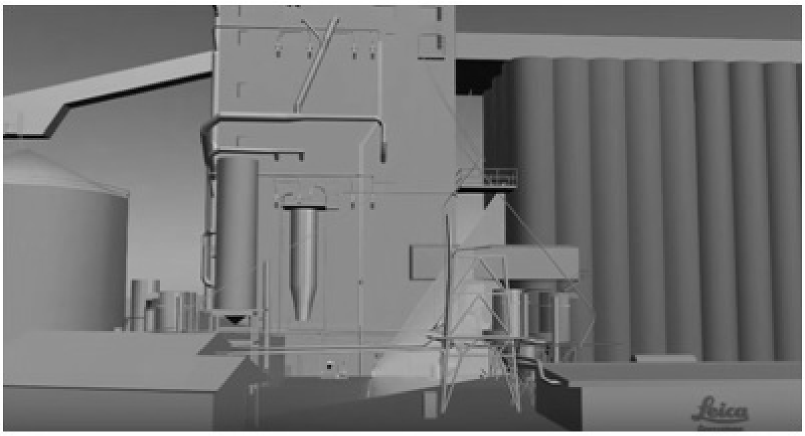

Fig. 2. An example of the sweep
source: www.youtube.com/watch?v=1lDO1UevAJI

When the laser beam shoots an obstacle terrain, the laser beam is reflected from obstacles and resubmitted to the scanner. So, based on the detected by the sensor the reflected signal of sufficient power, the distance between the scanner and the measured point can be calculated. It is possible due to the phase shift analysis of the wave or the traveling time between laser to object and back to laser, which was previously mentioned (Pudło 2006). The scanner calculates the distance measurement to which is assigned the horizontal direction and the zenith of the emitted beam. What is more it also record the intensity of the reflected signal and changes of the angle of the internal mirrors rotation. Based on the measured distance and the angle of the mirrors it is possible to clearly interpret the measured points and the determination of their position adopted in the spatial polar coordinate system X, Y, Z.

Fast data acquisition with the shortest time measurement makes terrestrial laser scanners an attractive alternative to the classical surveying equipment. Unfortunately because of the very high cost of hardware and software, they are available only for a small group of customers. These devices allow us to obtain from a dozen to hundreds of thousands of points per second, creating a three-dimensional image made from a set of points – a point cloud with X, Y, Z coordinates and the intensity of the reflection parameter, often called the "fourth coordinat". This enables to conduct more detailed analysis of the scanned object than based on data obtained using traditional measuring equipment (Hejbudzka, Łata 2013). However, we should be aware of the impact of various factors during the scanning e.g. the atmospheric conditions (Hejbudzka *et al.* 2010). In addition, it is worth paying attention to such parameter as the scanning resolution, because it can significantly affect the modeling and the reliability of the results obtained (Łata *et al*. 2015).

The point cloud is also characterized by other inconveniences such as e.g.: (Kamiński *et al.* 2008)

- a huge number of obtained data, among which there are also these unnecessary,
- lack of control measurements,
- occurrence of so-called "dead spots" caused by a lack of full visibility of the object that was scanned or unfavorable measurement conditions,
- occurrence, hard to directly indicate, gross error, eg. when the laser beam passing through the transparent object.

To obtain a spatial model of the object all of the acquired point clouds need to be combined into one set using one form several registration methods (Hejbudzka, Dumalski 2015). After registration the data the filtration process is conducted in which the points from point clouds that do not represent the object are removed. The resulting point clouds can be used to create a wire-frame or surface 3D model.

The process of creating point clouds from digital photos

The 3D modelling is often related with the reconstruction of objects based on photos. In photogrammetry method, having just a few photos and data, which provide definition of camera situation during taking photos, are enough to generate model of object.

The main issue during the acquisition of point clouds from terrestrial photos is the correlation process of the photos (image matching). This process involves the identification and measurement of homologous points on two or more photos. There are three methods for correlating photos:

- Area Based Matching focuses on the analysis of the group of pixels (the grayscale or, in the case of color photos, one of the channels). In this method a small fragments of images so-called image patches are used to compare. The similarities of these fragments is determined based on the correlation or the known least squares methods.
- Feature Based Matching uses a comparison of the edges or other objects that are homologous to many photos. This similarity is calculated as a function of the cost.
- Symbolic Matching in contrast to the two previous method does not used geometric similarity to compare the process of images. This method is based on a comparison of topological properties of the objects. These properties may relate to grayscale or objects found in the photo (Kurczyński 2014).

The process of photos correlation allows us to conduct the external orientation of the photos to show the location of the camera that existed during shooting.

Unfortunately, created in that way point clouds contains a number of points that have been incorrectly correlated. This is due to noise in the photos and unreliability algorithms responsible for matching the homologous points. Prior, to further processing data, the filtration should be carried out. Similarly to the point clouds acquired by laser scanner also in this case we can create a wireframe and surface model.

Due to the increasing interest in techniques of 3D scanning, photogrammetry has become one of the most frequently used and spectacular methods to convert the objects from the real world to the virtual one as the 3D models. A wide range of available softwares which use advanced algorithms give us the possibility to generate 3D models in a uncomplicated, requiring no need for precise determination of the camera image processing way. The advantages of this method consists of a small amount of work and a set of field equipment required in the form of amateur camera and a laptop with standard parameters.

The process of creating point clouds from the Kinect sensor

Kinect was originally designed as a sensor for the XBOX 360, which allows users for interactive entertainment without additional controllers. Due to its construction and functionality the widely available software were designed that enable to use the sensor to create 3D models.
The inside part of this device is mostly composed of the following items (Fig. 3).

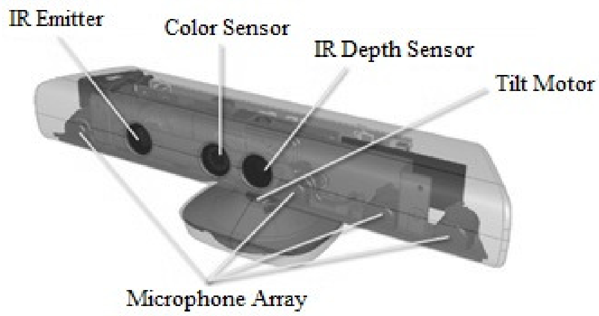

Fig. 3. The construction of the Kinect sensor
Source: https://msdn.microsoft.com/en-us/library/jj131033.aspx

The Table 1 shows the detailed contents of the controller Kinect with the descriptions of each element.

Table 1. A detailed description of the elements of Kinect sensor (Kopniak 2012)

Element	Description
Microphone Array	The set consists of 4 microphones that are used by speech recognition. These microphones have the function of noise filter.
Infrared Emitter	It emits beams of infrared light.
Infrared Depth Sensor	It reads the infrared beams reflected back to sensor and creating a 3D model space and the objects found in it.
Tilt Motor	Adjusts the position of the sensor automatically depending on the size of the tracked objects.
Color Sensor (RGB color camera)	It works like a webcam – sent a series of images to a computer with a speed of 30 frames per second and data in a 1280x960 resolution.

Additional components necessary to operate the Kinect sensor as a scanning device is a laptop and power adapter.

The scanning process begins with the slow and smooth movements of the user around of the scanned object with a Kinect sensor. This procedure gives the possibility to track and capture the characteristic points of the object. Based on the displacement of the sensor and in relation to these points its trajectory is determined (Kopniak 2012). Possible scanning range is from 0.4 m up to 6 m.

Infrared emitter emits projections of a known pattern creating a grid of points. Depth camera is the receiver of the rays reflect transmitted by the emitter and based on the deformation of pattern the depth map is created. That technique is called structured light. The depth data provides reconstruction of object in real-time. Additional information provided by the controller is an RGB image recorded by the built-in camera. Fig. 4 shows the simply work scheme of the Sensor Kinect (Borenstain 2012).

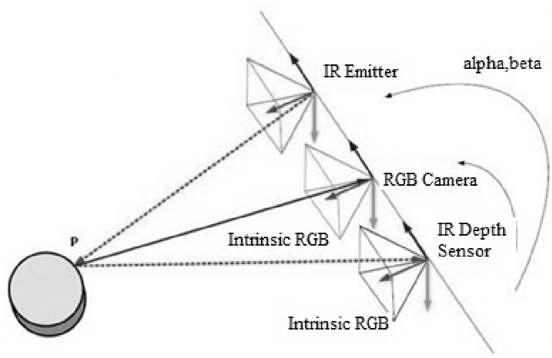

Fig. 4. The operation principle of the Sensor Kinect
Source: https://fabrizio89.files.wordpress.com/2014/08/depthcamera.jpg

By measuring the actual depth the coordinates of the infrared camera system are determined. These, in turn are converted to RGB camera system. Next terrestial coordinates are calculated to the pixel coordinates, which are broadcast colors from the RGB image.

As a final data we obtain a mesh which can be easly converted into a point cloud. However even though the Kinect captures dense 3D model still noises are occured as "gaps" on an examined object. Another type of issue which caused a several times a need of repeating or protraction of reconstruction was losing of geometry and track of object by Kinect sensor.

An example of 3D models using selected methods

Comparison of the three above-mentioned measuring methods was performed on the example of gypsum cast hand (Fig. 5).

Fig. 5. The gypsum cast hand

The gypsum cast hand was measured using three methods described in this article namely: laser scanning, photos with a digital camera and the Kinect sensor Xbox 360. Scanning was taken from three positions with a resolution of measurement 1x1 mm at a distance about 3m. By scans registrations the obtained point clouds has approximately 1.3 million points. The resulting resolution of the scanned hand is much greater because of the registrations of 3 scans and amounts to a fraction of millimeter. Fig. 6 shows the scanned gypsum cast hand in the point clouds.

Fig. 6. The point clouds of the hand obtained in Leica Cyclone program

Model from the second method was performed in the Remake software using 41 images taken with a digital camera Lumix Fz1000, with a resolution of 2 MPx single images. The result of modeling shows Fig. 7.

Fig. 7. Hand model obtained using the ReMake software Autodesk company

The next figure (Fig. 8) shows the model of the hand obtained by using device Kinect Sensor Xbox 360 and the Skanect software.

Fig. 8. Hand model obtained using the Sensor Kinect device

The created 3D models were printed out on a 3D printer for visual evaluation of received models. The Fig. 9 shows the results of the prints.

Fig. 9. The 3D models printed out on a 3D printer

Conclusions

Analysis of 3D models obtained from the three selected methods indicates that the best results gives the photogrammetric method. Model obtained from the pictures is the most realistic and gives many details (Fig. 7). The worst result gives the model acquired by using the Kinect Sensor device. In the presented example there are some "gaps" in the 3D model on the thumb of the scanning hand. The resulting gaps have already appeared at the time of scanning during the data collection. Also, the details have not been so thoroughly exposed as it is in the case of the model with photographs. Similar feeling can be applied observing the cloud point, obtained with a laser scanner. Certainly, the measurement error distance (4mm), error edge, which is often found in the laser measurement as well as the structure and texture of the object have a great impact on the final results of the data from the terrestrial laser scanner. The alternatives method to the laser scanning discussed in this paper show the possibility to generate a 3D model in far cheaper and less complicated way. We are sure that these alternative methods will find a lot of interest among researchers and enthusiasts in variety applications. The authors will continue their studies concerning usefulness of the photogrammetric method and the Sensor Kinetic device testing them in the new objects and under the different conditions.

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