



## INTERNATIONAL JOURNAL OF INFORMATION TECHNOLOGIES, ENGINEERING AND MANAGEMENT SCIENCE

### Impact of normal calculation on object reconstruction in a 3D environment

**Pavol Kudela, Michal Palčák**

University of Žilina, University Science Park, Slovak Republic  
pavol.kudela@uniza.sk, michal.palcak@uniza.sk

#### Abstract

Currently, the progress of virtual reality is in a great boom. This form should not have only an educational character, but it must contribute to the opportunities to enhance the attractiveness of cultural heritage or to provide a basis for the future development of the automotive industry. Also, creating virtual environments for the gaming industry is another integral part of digitization, based on accuracy and photorealism. Each project focuses on obtaining the most accurate data from the scanner to capture all the details. One of the crucial tasks is optimisation and post-processing of data. Nowadays, it is possible to process data in much more available software, but it is necessary to understand the importance of selecting the way of data processing. This article describes a practical procedure for creating an object's mesh, based directly on the registered data. Each information did not have any correction, and data was loaded into the selected software environment. In the introduction of this article, the main issue was discussed and subsequently applied to the specific model. However, it should be considered, that it is not possible to understand this process as a default, but as a process which enables to approach the projects individually, to use the time efficiently, and with the correct settings of each function.

**Keywords:** normal, vector, meshing.

#### Introduction

The history of 3D scanning dates to ancient Egypt. At that time, the first 3D mummy statue was created, and rare materials such as linen and various types of plaster were used. Life was difficult, but not only in terms of hard work but mainly in terms of time consumption. Later, in the 1960s, the oldest 3D scanners have been used based on contact probes, and these 3D model probes had to be in direct contact with the scanned material. However, in the late 1980s, the advent of innovations came in the form of optical technology that helped to minimize the scanning time as well as to increase the quality of the scanned object. Today, there is a massive 3D scan expansion in almost every area. Therefore, not only the quality demand has increased but also the requirement to obtain the colour of the individual points on the scanned object. In connection to growing demand, the hardware device (further referred to as HW) requirements increased, to be able to process large amounts of data. Also, Table 1 presents an example of the scanning difficulty, mainly in terms of obtaining data from scanners. As we are in

a period of mass digitization and applications of smart solutions, the necessary precondition for successful projects is the consistent digitization of environments and objects. Now, the actual scanning through different types of scan devices offers many options, such as obtaining many points in a short time or gathering some information about the colour and texture of the object. It should be mentioned and considered that there are some limitations to this process. These limitations could be summarized as follows:

- The continuously growing demand for HW for processing large amounts of data.
- The method of triangulation must be differentiated individually in each case.
- Issues with the illumination of large areas and waiting time for optimal outdoor conditions.
- Issues with Field of View (FOV) at ambient light.
- Issues with the optimum texture and colour of materials and problem with translucent and glossy surfaces

- The strong correlation between FOV and resolution
- The issue with the density of points per second, when scanning objects

From the problems mentioned above, it can be concluded that there is a need for adjusting the optimal lighting conditions, but also focusing on the scanning device itself. This scanning device must scan an object or environment in the shortest possible time with the minimum trace error. Subsequently, after scanning, this point cloud is transmitted to an adequate hardware device, to be able to process a large amount of data in terms of calculation.

**Tab. 1 Increasing requirements of components in the process**

Year	CPU/RAM	Image memory	HD capacity	Camera resolution
1980	64 KB	512 KB (*)	5 MB	(**)
1985	512 KB	2 MB (*)	20 MB	256 KB
1990	2 MB	16 MB (*)	100 MB	1 MB
2000	200 MB	100 MB	GB	4 MB
2010	4 GB	2 GB	TB	8 MB
2014	64 GB	32 GB	10 TB	16 MB

Source: [1];

(\*) with a special memory architecture

(\*\*) videos from cameras

### Theory of normal vector

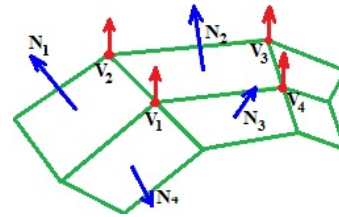
In recent years, a growing number of scanning devices have emerged on the market, capturing much more details within their capabilities. As the quality of the captured details increases, the amount of data transferred to the virtual environment also increased, whereby the cloud point data is subject to the processing process itself. In this environment, based on many differential geometrical properties, the resulting scanning defects can be calculated to provide processed modelling.

There are several software solutions capable with a point cloud and its modification which can generate a mesh object, such as:

- Polyworks
- Cloud Campare
- MeshLab
- Geomagic
- And more other

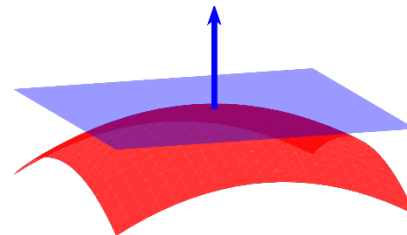
When working in point cloud software (such as XYZ file format), first, it is necessary to understand the

geometric structure of the scanned object and the quality of the spot cloud. In the other case, the emphasis is placed on the accuracy of scans registration to minimize the deviation with the least possible point cloud distortion. This process performs in a Euclidean space, based on the Cartesian coordinate system. It means that in the Euclidean space delimited by the Hilbert axiom system, each point of the system has a defined position (x, y, z centred in 0). Based on the source of data, from the camera (such as position, orientation, etc.) or the scanner, the information must be completed into individual points, in its complex file, that will represent the scanned object. After obtaining such amount of points, it is necessary to define the normals for the next process, which will determine the orientation of the given object surface, texture and the like. A normal vector can be assigned from a focal plane, joined with the plane of the nearest neighbours, or by each cloud point. (See Figure 1).



**Figure 1 Normal vector from the surface; Source: [3]**

A normal vector is a vector which is perpendicular to the surface at a given point. In three-dimensional space, it is a vector which is perpendicular to the surface of the plane that has the same tangent point as the overlay plane of the object's surface.



**Figure 2 Vector surface; Source: [4]**

The normal vector, according to [2], at a point (x0, y0) on a surface  $z = F(x, y)$  is given by:

$$N = \begin{bmatrix} f_x(x_0, y_0) \\ f_y(x_0, y_0) \\ -1 \end{bmatrix} \quad (1)$$

where  $f_x = \partial f / \partial x$  and  $f_y = \partial f / \partial y$  are partial derivatives.

A normal vector to a plane specified by:

$$F(x, y, z) = ax + by + cz + d = 0 \quad (2)$$

is given by:

$$N = \nabla f = \begin{bmatrix} a \\ b \\ c \end{bmatrix}, \quad (3)$$

where,  $\nabla f$  denotes a gradient defined by the degrees of grey colour, or other mathematical methods use basic geometric shapes.

The equation of a plane with a normal vector  $n = (a, b, c)$  passing through  $(x_0, y_0, z_0)$  is given by:

$$\begin{bmatrix} a \\ b \\ c \end{bmatrix} * \begin{bmatrix} x - x_0 \\ y - y_0 \\ z - z_0 \end{bmatrix} = a(x - x_0) + b(y - y_0) + c(z - z_0) = 0 \quad (4)$$

However, if it is a curvature, a tangent vector is defined, and the parameterization depends on the arc length and the angle. If the vector must be on the curve, it must be displaced by  $(f(t), g(t))$ . Finally, the unit normal vector is:

$$N = \frac{a \times b}{\sqrt{|a|^2 |b|^2 - |a \times b|^2}} \quad (5)$$

### NN (Nearest neighbours) method

In general, the calculation of the algorithm to find the closest points is very simple. But, a disadvantage of this algorithm is that each mesh defined area is diverse and thus more complex for each new point. In practice, it means that we can have a large amount of data, where we get a lot of new elements, and it is always necessary to look for the optimal distance between them. This type of method recognizes the closest points, according to the set values, which connects and after creating a polygon and a normal vector. It is a Euclidean space defined by the vertexes (points) and the imaginary lines determined by the Voronoi diagram. This method divides a given area with points into individual subareas. In the resulting comparison, it is possible to see the dual data structure defined by the new triangulation network and the replaced originals. (See Figure 3).

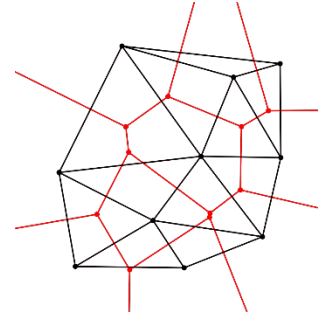


Figure 3 Voronoi diagram; Source: [4]

### A practical example of the effect of orientation of normal vectors on the resulting mesh from the perspective of object reconstruction

For the application of the theoretical part, the chosen object was scanned, followed by suitable triangulation and point cloud processing. This object has been defined as moderately difficult due to its height and weather conditions. A laser scanner with a range of up to 300 m was used to scan the object. Also, this scanning device is based on transmitting an optical laser and measures the time and length of the reflected beam. The wavelength specified for this device is 1550nm, and the beam divergence is 0.19mrad. The object scanning required a precise theoretical preparation, due to the surface difference, where, it was necessary to define the scanner location and reference spheres position. In the scanning process, it was necessary to achieve the highest accuracy between individual scans, and therefore, the emphasis was placed on the optimal reference point distance. From the facts mentioned above, the total number of scanner positions determined was 9. Such a figure predicted adequate positions for capturing the object, in terms of diversity of surface. During the scanning process, it was necessary to adjust the device for the bright weather conditions, because the day was sunny. Therefore, it was essential to set up parameters such as resolution and quality to comply with the weather conditions, because, it affects the final quality of an object scan. After the scanning, the point clouds have been imported into the software environment for registration. There are several ways to register individual scans. But, in this case, a method, defining reference points, or spheres, has been used. Reference spheres play a significant role in the registration process as the sphere's location and position determine the degree of accuracy deviation. The export of the scanned object was in point cloud library format (PCL), which represents information of every single point with RGB (red, green, blue colours). In Figure 4, we can see the imported data of each registered scan.

After registration of scans, the meshing process of the

object will start in the open source environment. In this environment, it is possible to work out the empirical calculations.

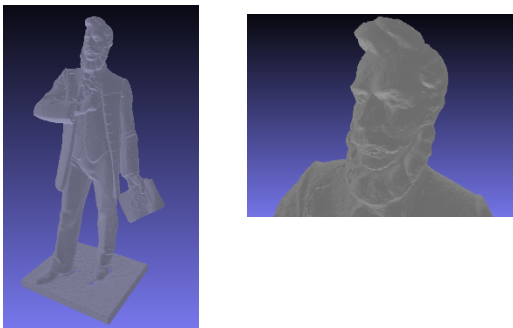


**Figure 4 Point cloud data**

The fundamental process for correctly performed triangulation in an opensource environment is the following sequence:

- Laser scanning (other software)
- Registering point cloud (other software)
- Export point cloud
- Import data to Meshlab
- Poisson-disk sampling
- Compute normal
- Surface reconstruction

From the triangulation procedure, already mentioned above, this area was selected to compare the effects of normals on the resulting triangulation. This area represented a section where there were flat surfaces, but also a rugged surface structure (See Figure 5).



**Figure 5 Scanning object/Comparison object**

There are several options [6] that define the maximum number of points in terms of optimization so that the result is less difficult to hardware. Disk sampling determines the radius of the Poisson-disc, which is half of the distance between the two closest points. This function provides a simple distributed set of points, better than the original object. In short, it is an equal distribution of points against a randomly

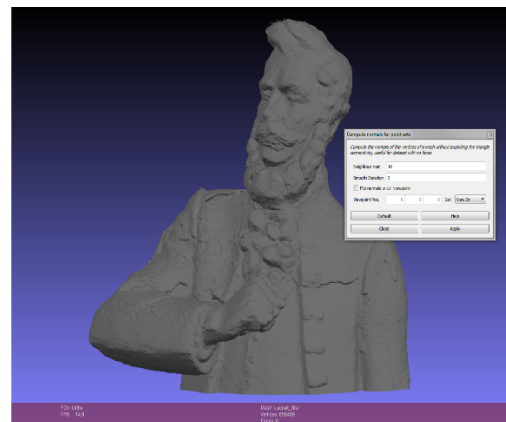
irregular generation points of the scanned object. From the result of the generated object, we can conclude, that when the points distributed evenly, there is less noise occurrence in the resulting object than in the reconstruction of the original object. The next step, to obtain optimization, is to simplify the model based on the point reduction function. In our case, it is an object with 877445 points. In terms of object optimization and shading, the total number of points was 390,855 (shown on the object on the right of Figure 5). When reaching this number, the detail and quality of the object should remain well preserved. (See Figure 6).



**Figure 6 Poisson-disk sampling**

After selecting the area, the calculation of normals has been worked out according to the procedure, mentioned above, and then subsequently, the model was simplified. When working with large amounts of data, the process itself is time-consuming, especially in the creation of a mesh, and the hardware configurations of computer assemblies are not always adequate for subsequent processing of objects. Therefore, the optimization of the size of the object, in terms of data, is formed, while maintaining a satisfactory surface structure.

In the MeshLab environment, a new window opens, offering a way of calculation of the normal (See Figure 7).



**Figure 7 Compute normal for point sets**



Within this option, it is advisable to identify the orientation of the normals, on the original object. And after that to properly adjust the settings, so the correct object reflection effect is achieved in the final texturing.

The figure below shows the effect of the parametric setting on the orientation and calculation of the normal for the object (See Figure 8).

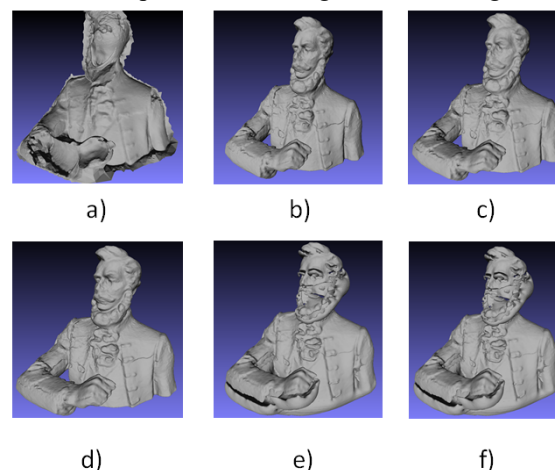


**Figure 8 Normal vertex a) without compute vertex, b) NN 10, c) NN 16, d) NN10 and camera pos. 100/100/100, e) NN 10 and flip, f) NN10 and flip and view dir. 1000/1000/0**

From the first figure (a) emerges that the recalculation of the normals points directed towards the growing position of the camera. So, all the normals are directed to the camera position and set as a default. Figures (b), (c), (d) are recalculated, based on the number of adjacent points determination and then the total number of normals is reduced. Any changes, in the parametric recalculation of these normals, affect the overall shading in extended areas, for example on the shoulder. The normals orientation plays a significant role in terms of shading, shown in Figure (e). From which, it is visible, that the parametrically calculated normals will significantly impact the illumination of individual parts.

The direction of normals (the Figure (f)) was predicted based on the normals orientation of the original image (a). Also, the parameters were set up to calculate the normals of each point, which makes their orientation to be unidirectional. From such calculated normals, in the following step, the model will be reconstructed. Based on the algorithm, this reconstruction assigns an elementary quantity to the defined area and points to the mesh. The advantage of this reconstruction is that it is very resistant to data noise. Also, its mathematical expression is the

calculation of all points at once without the need for heuristic distribution or mixing. After recalculating the point cloud to the area, an outcome is a mesh object. In representative samples of the parametric definition of normals, a recalculation will be worked out, and the result of this parametric setting is shown in Figure 9.



**Figure 9 Surface reconstruction: Poisson a) without compute vertex, b) NN 10, c) NN 16, d) NN10 and camera pos. 100/100/100, e) NN 10 and flip, f) NN10 and flip and view dir 1000/1000/0**

As mentioned above, this is a reconstruction setting, so that must be as accurate as possible. In this case, the more sensitive parameters on calculation have been used, mainly in terms of counting extension, and for the mesh creation, so the reconstructed object should have enough of new areas to copy the original.

The result will be an object whose number of peaks will be reduced by 15% compared to the simpler one.

Figure 9 shows the impact of normals calculation on the overall reconstruction result. In the first case, there is an example illustrated (see a, Figure 9) in which the user does not recalculate the normals but uses their original orientation. Therefore, the object indicates some deformation, which is not possible to correct it in another software environment.

In the three following outputs (see b, c, d, Figure 9) the models are similar. However, image c is better, in terms of quality, because the surface of the object was copied mainly from the point cloud. In the final output, the great details, focusing on the selected parts, are achieved. The last two images (See e, f, Figure 9) demonstrate that an influence of normals rotation against the original has an impact on the mesh calculation. In this case, it was not possible to use the rotation function as the reconstruction was with significant distortions.

## Conclusion

The issue of solving normals in postprocessing has a significant impact on the resulting mesh. In each case, this is an individual approach to the data obtained. Each scanner stores information about every single point received in the desired format, and this format acquires certain information after importing into the required environment. Therefore, it is essential to process this information correctly as well as to set the right orientation. However, if the correct orientation of normals not achieved, it might lead to the malfunction of some functions.

And, in the outcome, when texturing, the desired shading would not be achieved. However, if done correctly, it creates a good condition for implementation and reality in a virtual environment.

## Acknowledgements

This publication was realized with support of Operational Program Research and Innovation in frame of the project: ICT products for intelligent systems communication, code ITMS2014+ 313011T413, co-financed by the European Regional Development Fund.



## References

- [1] 25 Years of High Definition 3D Scanning: History, State of the Art, Outlook [Online]. Available: [https://www.bcs.org/upload/pdf/ewic\\_ev14\\_s19\\_paper3.pdf](https://www.bcs.org/upload/pdf/ewic_ev14_s19_paper3.pdf)
- [2] Wolfram MathWorld, The webs most extensive mathematics resource: Normal vector [Online]. Available: <http://mathworld.wolfram.com/NormalVector.html>
- [3] Basic ambient light: [Online]. Available: <https://www.csee.umbc.edu/~rheingan/435/pages/res/gen-11.Illum-single-page-0.html>
- [4] Wikipedia: Normal (geometry): [Online]. Available: [https://en.wikipedia.org/wiki/Normal\\_\(geometry\)](https://en.wikipedia.org/wiki/Normal_(geometry))
- [5] Wikipedia: Delaunay triangulation: [Online]. Available: [https://en.wikipedia.org/wiki/Delaunay\\_triangulation](https://en.wikipedia.org/wiki/Delaunay_triangulation)
- [6] Sample Elimination for Generating Poisson Disk Sample Sets [Online]. Available: <http://www.cemyuksel.com/research/sampleelimination/sampleelimination.pdf>