INTEGRATION OF TERRESTRIAL LASER SCANNING AND GIS TECHNIQUES

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Abstract: *Terrestrial 3D laser scanning provide to surveyor an accurate and efficient way to collect and present field data. The acquired point cloud, a detailed and rich data source can be exported in order to be used in different software packages including GIS environment. In this paper we will present the use of terrestrial laser scanning data in a GIS software in order to process, visualize and obtain final deliverables.*

1 Introduction

Many scientists consider that GIS technology was developed as a consequence of the world necessity for modelling its anthropic or natural phenomena in real time. Other consider that the impulse needed was the one coming from the cartographers that wanted to reduce the costs and time needed to produce cartographic products. No matter what the burst was, it is important to see that even if GIS technology was introduced at first as a tool for generating efficient geographic products, nowadays it acquires more importance and conquers many diverse and multiple domains.
GIS has an enormous capacity of collecting and storing data. It is able to create a mould where data coming from different sources and with different gathering methods can be processed and analyzed so that all the results bear the proficiency stamp. A plus is the usage of different results provided by the analysis process: maps, plans or reports can be used efficiently in order to adopt the best strategies for studied or unforeseen problems.
Technologies as GPS – Global Positioning Systems, CAD - Computer Aided Design, Photogrammetry and Remote Sensing, - to name a few, combine their technological and professional resources to create a super powerful tool called GIS. This tool has the ability and complexity needed to combine and process data.
In this paper we will present the way how surveying technology such as Terrestrial Laser Scanning can be an important and rich data provider for GIS and to demonstrate that GIS is a powerful tool in and for Surveying.

2 Fundamental concepts

Nowadays, due to continuous technological progress in every profession and every industrial branch appear new devices that affect the natural order of workflows, improving them. For instance, GIS technology "is constantly affecting the way many professions operate, particularly surveying" [1].

2.1 Terrestrial Laser Scanning

Terrestrial Laser Scanning is a modern, active and contactless technology, suitable for achieving spatial data with high speed and precise. This technology known in the literature, also, as Static Laser Scanning is able to record a specific area or an object in a digital format. The result is a point cloud, which can be used to extract information point by point, line by line or surface by surface [4].

In the laser scanning community there is no universal terrestrial laser scanner. Some of them are used for close distances, other for medium or long distances. A classification of terrestrial laser scanning can be made taking into account the measuring principles: time of flight, phase difference or triangulation. Also, they can be classified into camera or panoramic scanner. The former have a fixed rectangular field of view (60ºx60º) and the latter have a field of view 360º in the horizontal plane and up to 310º in the vertical plane [3].
The provided spatial data are precise and can be used in an efficient way in different applications in order to obtain a DTM, DSM, profiles, ASCII files and other deliverables.
A general overview of the followed terrestrial laser scanning workflow is presented in Terrestrial Laser Scanning workflow

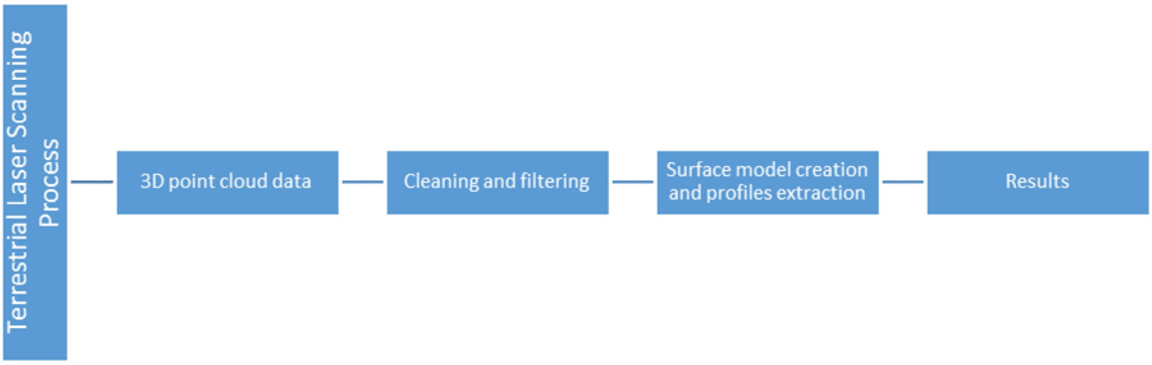


Fig. 1 Terrestrial Laser Scanning workflow

2.2 Geographical Information Systems (GIS)

A GIS database entity is mostly associated with data compatibility. Geographical Information Systems have the huge ability to combine, by more simple or more complex methods, different inputs, such as classical maps, GPS measurements, Remote Sensing data or data coming out of point clouds generated by the Terrestrial or Airborne Scanning processes. This conglomeration of data can be later used as a background for spatial-temporal analysis. These systems also offer the possibility to perform very complex and correlated analysis, which is virtually impossible using conventional techniques. The storage and analysis of both graphical and textual (also known as non-graphical) data can be performed by a computer that has the proper hardware and software capabilities, the human influence being also present. As a first conclusion, we can say that the use of GIS can achieve your goals in a more accurate, easier and faster than conventional methods [6].
In the next image (Fig. 2) we presented a data workflow in a GIS, from the collection of data to the users.

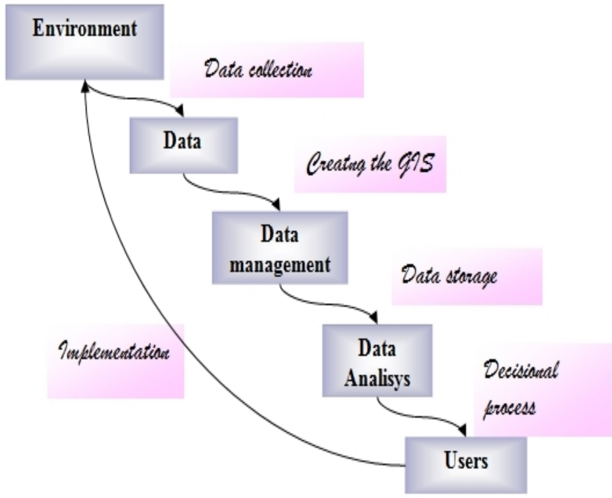


Fig. 2 General GIS data flow

3 Study case

In the context of scientific innovations, Geographic Information Systems have had an important role as an integrating technology [2]. Considering the power of GIS as an integrating technology, the authors considered appropriate to put the accent on the use of point clouds that resulted from a Terrestrial Laser Scanning process in this technology.

The study case resulted as cooperation between ESRI and Leica products. We used from ArcGIS two different modules – ArcMAP and ArcSCENE in order to analyze and visualize 2D or 3D data. The main data source for this study case was the Leica ScanStation 2 Terrestrial Laser Scanner which generated the point cloud, used latter in a processing task in Leica Cyclone software. The data that resulted were used as such, without applying too many processing procedures.

When we say GIS we instantly think of a complex database system that consists of graphical and non-graphical (tabular) data that refer to the same object. Graphical and non-graphical data are stored together, creating a model of the field if the layers have the same reference frame. Therefore, when creating a GIS, the coordinate system must be the same for all the layers from the model.

The point cloud resulted (Fig. 3) from the scanning process has been filtered using the Leica Cyclone software and had been saved as *.txt and *.csv files in order to be used in the GIS analyses. The files contain X, Y and H coordinates and it is this thing specifically that allowed us to consider the *.txt file as the original “base map” and use it latter on for different GIS tools or analyses. The point cloud file could have been used as a topographic base for analysis. One of the main positive sites of GIS is that is uses 3D models for data representation. That is why we used the information kept in the H column to create the TIN (Triangulated Irregular Network) and the IDW (Inverse Distance Weighting) or Kriging methods for 3D modelling.

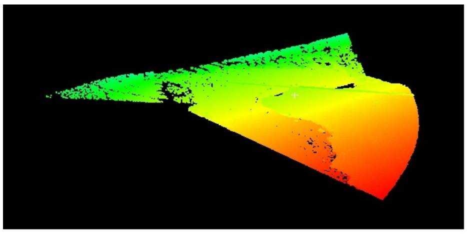


Fig. 3 The resulted point cloud

The TIN model (Fig. 4) is the alternative for the raster model when it comes to continuous surfaces. In the TIN model an area will be represented with a series of triangles and every node of the triangle has a complete series of coordinates. There are two other important elements when we are talking about TIN models: the breaklines and the mass-points. These two entities give information and restrains on how the surface will look like. TINs are created automatically using the Delaunay triangle criterion, which says that no vertex should lie within the interior of any of the circumcircles of the triangles in the network [7].

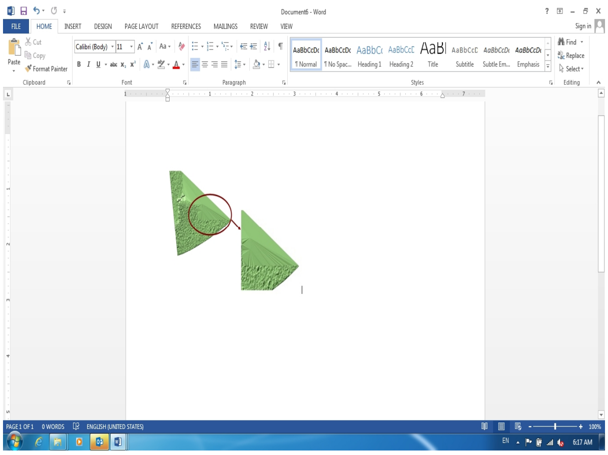
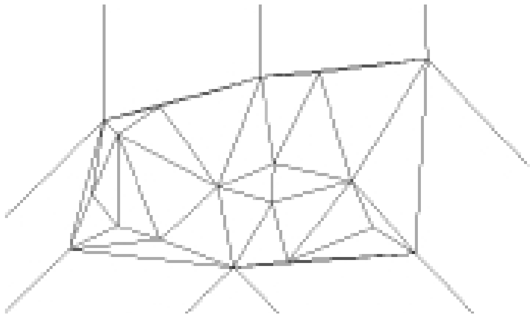


Fig. 4 TIN model in ArcGIS

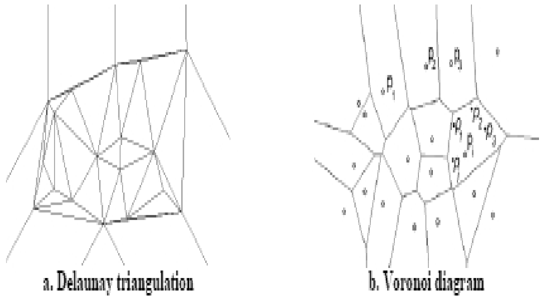
The geometric equivalent of the Delaunay triangulation is the Voronoi diagram (Fig. 5). The main idea of the Voronoi diagram is to divide the space into convex cells and to create regions around each known site P_i such that every point ρ from the region is closer to the point P than to any from the other sites [5]. The Voronoi diagram has three important topological elements [1]:

- The Voronoi point – it is considered to be a Voronoi point, the point that is placed at equal distance from three different sites;
- The Voronoi line – it is considered a Voronoi line, the line given by the points which are equidistant to two sites in the plane
- The Voronoi polygon.

TINs are the most used ways to create 3D models. Another way to generate 3D models are by using the methods of interpolation. Many GIS software – and not only GIS – have proper functions that describe and use different methods to interpolate data. Every interpolation methods has positive and negative parts. For example, if we want to create a smooth, flowing representation model we can use the Inverse Distance Weighted Interpolation, Kriging or Natural Neighbors, to mention just a few.



a. Delaunay triangulation



b. Voronoi diagram

Fig. 5 Delaunay triangulation vs. Voronoi diagram [1]

Inverse Distance Weighted Interpolation, also known as IDW, is the simplest interpolation method. This method states that the value of un-measured points can be approximated as a weighted average of the values of the measured points that lie at a certain distance of the point of interest. The solution is given by:

$$P_i = \frac{\sum_{j=1}^{G} \frac{P_j}{D_{ij}^{n}}}{\sum_{j=1}^{G} \frac{1}{D_{ij}^{n}}}$$

Where P_i is the value at location i; P_j is the value at sampled location j; D_{ij} is the distance from i to j; G is the number of sampled locations; and n is the inverse-distance weighting power. The value of n, in effect, controls the region of influence of each of the sampled locations. The inverse-distance weight and the region of interest are reversed proportional. As n increases, the region of influence decreases until, in the limit, it becomes the area which is closer to point i than to any other. When the weight n is set equal to zero, the method is identical to simply averaging the sampled values. As n gets larger, the method approximates the Voronoi tessellation procedure. Usually, the value of n is set arbitrarily. Values of 1.65 and 2 were used for n by Kelway and NOAA, respectively, for interpolating rainfall, while the ARMOS model recommends the use of values ranging from 4 to 8 for interpolating oil pressure heads [8].

In scientific literature there were specified some limitations of the Inverse Distance Weighted Interpolation. The major limitation is that estimates are bounded by the extrema in the sampled values. Additionally, the radial symmetry which this procedure imparts to the data obscures the effect of linear features such as ridges or valleys. For $n \leq 1$, the derivative of the interpolated surface is discontinuous at the sampled locations, while for $n > 1$, the surface is flat at these sampled locations [8].

The Kriging interpolation method, even is mostly alike IDW, uses more complex and more refined functions based on the measurements made in a certain spatial arrangement.
According to Davis (1986), when the Kriging method is concerned, a weighted mean of the sampled values is evaluated for each node, such that the estimation error is minimized by solving simultaneously the set of equations:

$$P_i = \sum_{j=1}^{G} W_j P_j$$

$$\sum_{j=1}^{G} W_j = 1$$

$$\sum_{j=1}^{G} W_j \gamma(D_{kj}) + \lambda = \gamma(D_{ki}) \quad k = 1, 2 \ldots . G$$

Where W_j is the weight for location j; λ is a variable added to minimize the estimation error; and γ (D_{kj}) is the semivariogram value between points k and j [8].

In Fig. 6 are the presented the models that resulted as an application of the IDW and Kriging interpolation methods, based on the initial point cloud data.

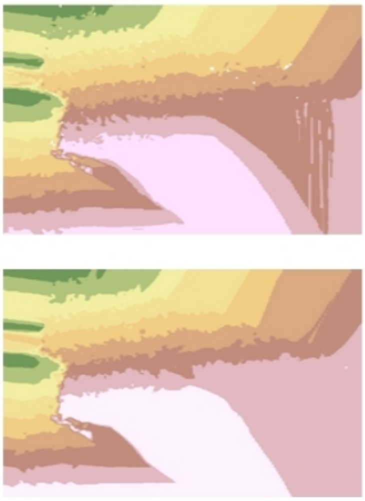


Fig. 6 Interpolation methods – IDW (up), Kriging (down)

The generated surface models can be used in a GIS software, where different developed tools can help a Surveyor to create other elements, such as contours at a desired interval or determine the slope, that are necessary for creating a proper topographic plan. Another application, based on Terrestrial Laser Scanner point cloud is related to solar energy. With the help of ArcGIS, a surveyor can determine a proper placement of photovoltaic cells by computing the received solar radiation of a certain point from the scanned area. This is a very interesting application, if we consider the world tendency of using renewables (Fig. 7).

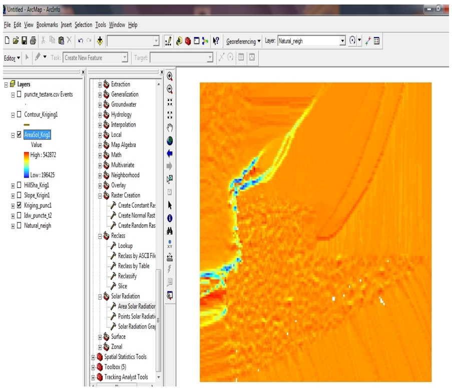


Fig. 7 Solar radiation computation

Even if the DEM is easier created and manipulated in ArcGIS, ArcSCENE allows us to visualize it better. This ArcGIS module establishes a lighter connection between the surveyor, who understand topographic data from the professional point of view, and the beneficiary, who most of the time comes from the non-professional area. Using ArcScene, a surveyor can explain how the land actually looks like and explain to the customer things like flooding, for instance. By exaggerating the scale of heights, in comparison with the other coordinates, the natural breaks from the field could be easier seen.
In Fig. 8 we showed the model that resulted after applying one interpolation method, exaggerating the elevation scale by 5. The exaggeration scale helps the user see a certain terrain imperfection. With lighter colors (red, orange, and yellow) are presented the lower values of the surface, with blue and green the higher ones.

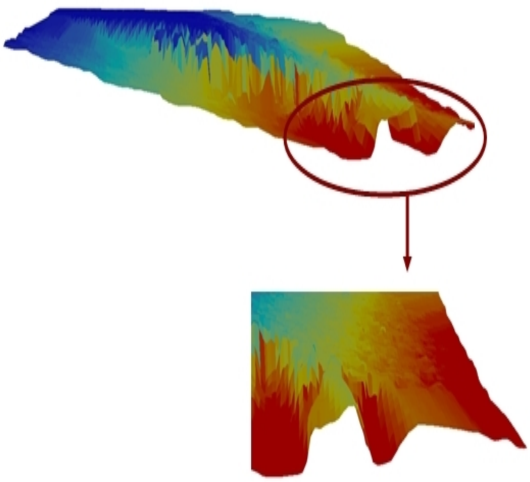


Fig. 8 Surface model seen in 3D – ArcScene

The point cloud that we used was just a set of trial data that was enough to help us create an algorithm that could be used by any surveyor to import any type of data in ArcGIS.

The same algorithm could be applied to larger point clouds obtained from LIDAR or Bathymetric measurements.
The workflow can be permanently adjusted according to ones needs or computer capabilities. The steps of the workflow we propose are presented as follows in Fig. 9.

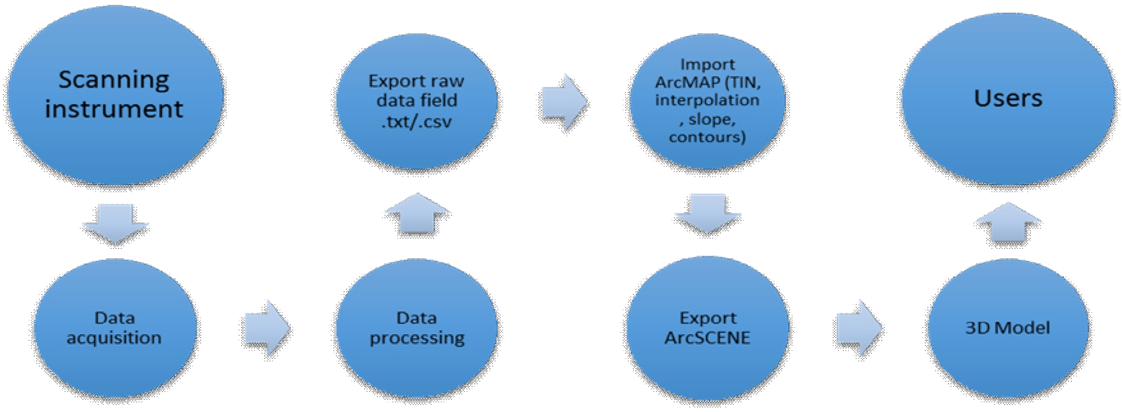


Fig. 9 Typical workflow

4 Conclusion

Many survey instruments, 3D Laser Scanner included come together with its specialized software package that help the collected data be processed and visualized.
Used in a GIS environment, the point cloud data may vary according to the application in itself. As described earlier raw point cloud can be used to create all the necessary products that a surveyor may need: earthwork and contouring functions, DEM modeling and visualization, maps or any other product that will serve the necessities of the customer.

5 References

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