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ORIGINAL PAPER

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COMPLEX GEODETIC AND PHOTOGRAMMETRIC MONITORING OF THE KRAĽOVANY ROCK SLIDE

Štefan Sokol[1*], Marek Bajtala[1], Miroslav Lipták[2], Peter Brunčák[3]

[1] *Department of Surveying, Faculty of Civil Engineering, Slovak University of Technology in Bratislava (Bratislava, Slovakia)*
[2] *Terraprojekt, public limited company (Bratislava, Slovakia)*
[3] *Department of graphic documentation, The Monuments Board of the Slovakia (Bratislava, Slovakia)*
[*] *Corresponding author: stefan.sokol@stuba.sk, tel. +421 907 169 380*

ABSTRACT

Purpose	The aim of this paper is to assess the impact of input data density and diversity on surfaces obtained using the terrestrial laser scanning (TLS) method for creating digital elevation model (DEM). For this we can use several approaches, while we have chosen an intermediary parameter – volume calculation, which is in practice the most frequently requested requirement from surveyors.
Methods	Precise terrestrial measurement and terrestrial laser scanning were used to ensure that detailed knowledge about the surface and volumes of two piles of earth and a stone pit in comparison with theoretical defined surfaces was obtained.
Results	Mathematically defined surfaces generally have smooth shapes, and thus the effect of different density on the input data is less apparent in the final comparison of volumes. In our case the results for most of the different interpolation methods and the different density of the input data was less than 0.5%. From the experimental measurements of the two earth bodies and the quarry, which have an irregular shape with unsmooth surfaces, we can only test the relative precision of the calculated volumes to the data with the highest density. Experimental measurements in the area of the quarry, where the scanned surface was uneven and considerably different in height, confirmed the assumption that a vastly irregular surface should exhibit more significant variations than a smooth surface, but for the nearest neighbour method relative errors under 1% were achieved.
Practical implications	According to the results from the analysis above, the lower density of input data we have, the lower the precision of calculating volumes we can assume, but it is interesting that we did not achieved significantly worse results with strongly irregular surfaces compared to a less irregular surface.
Originality/ value	The input values for the analysis of theoretically defined surfaces were obtained by the calculation of integral calculus and earth-moving bodies and quarry from an experimental measurement terrestrial laser scanning method and were used in Slovakia for the first time.

Keywords
theoretical surface, terrestrial laser scanning, volume calculation, density and diversity of surface

1. INTRODUCTION

The computer environment together with software enables the creation of digital models of a selection of different types of interpolation methods. The choice and the employment specific interpolation method influence several factors that are linked with the character of the modelled area or the specific exploitation of the executed model.

The accuracy of the digital elevation model (DEM) is decisive in its use, which is in addition to terrain roughness, affected by the interpolation function, interpolation method and the attributes of the input data (Li, 1992; Li, Zhu, & Gold 2004; Aguilar, Agűera, Aguilar, & Carvajal, 2005; Chaplot et al., 2006). The most commonly used methods are interpolation and approximation, eg. Kriging, the inverse distance method, the nearest neighbour method and the splines method.

An important foundation for creating DEM is having a finite number of points on the surface. For the collection of spatial data, surfaces or objects from smaller scale surveying methods are usually used, such as conventional methods using universal measuring stations and methods based on GNSS and terrestrial laser scanning (TLS). TLS methods provide high accuracy input data, but on the other hand, if we get denser data collection, they are time consuming (Gašinec, Gašincová, Černota, & Staňková, 2012)

Theoretical assessment can be made on figures whose surface is generated on the basis of known functions of planar coordinates and the volume can be calculated using integral calculus (Yanalak & Baykal, 2003; Easa, 1998; Chen & Lin, 1991), or on the figures, where the exact volume is known (Yilmaz, 2009). Secondly, comparison of results obtained from measurements of different input data densities or by comparison with the results of various methods can be determined by their relative accuracy (Křemen, Pospíšil, & Koska, 2009). In this paper the theoretical surfaces and the surfaces measured by terrestrial laser scanning have been analysed.

2. ANALYSIS ON THE THEORETICAL SURFACES

For this purpose, we defined a rectangular area with the dimensions 20 × 30 m and its origin is given the planar coordinates $x = 0$ m and $y = 0$ m (Fig. 1). Subsequently, within this area and on its borders, we created sets of approximately regularly distributed points with a density from 20 mm up to 1 m (Fig. 1). In order to create the theoretical surfaces over the defined area, we used two functions for all sets of points:

- theoretical surface A: $z(x,y)=\sqrt{\frac{x\cdot y}{100}}$,
- theoretical surface B: $z(x,y)=7-\sqrt[3]{(x-10)^2+(y-15)^2}$,

where x and y are the planar coordinates of the points.

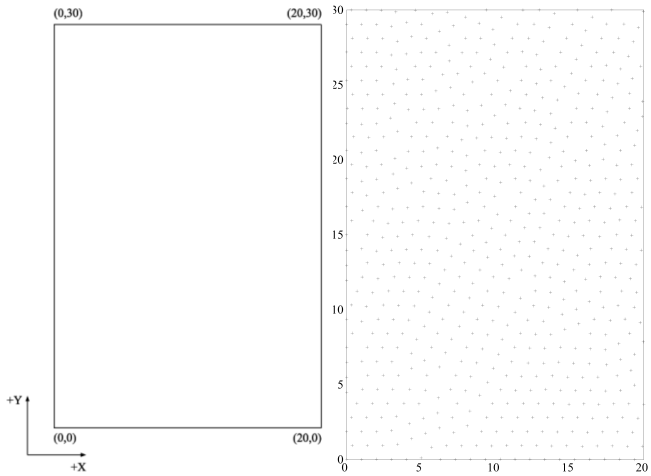

Fig. 1. Defined area (left) and a set of points with a density of 1 m (right)

Based on these sets of the spatial coordinates of points, we created the grid DEMs using the nearest-neighbour, the inverse distance squared weighted and the Kriging method from Surfer software. The grid size was adjusted according to the density of the source data (McCullagh, 1998). Graphical representations of the contoured maps and DEMs of both theoretical surfaces are shown in figures 2 and 3.

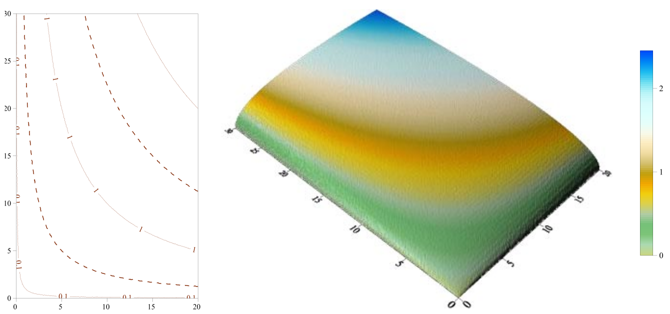

Fig. 2. The contoured map and the DEM visualization of the theoretical surface A

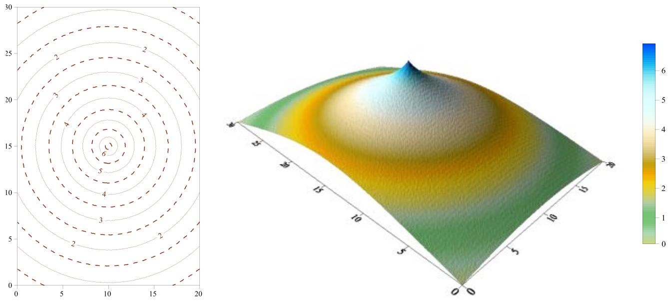

Fig. 3. The contoured map and the DEM visualization of the theoretical surface B

Calculation of the volumes from the generated DEMs was also carried out using the Surfer program and the cross-section method. As a reference plane we chose a horizontal plane with a height of 0 m. The correct values of the volumes were determined using the integral calculus:

$$V=\int_{x_{\min}}^{x_{\max}}\int_{y_{\min}}^{y_{\max}} z(x,y)\,\mathrm{d}y\,\mathrm{d}x \tag{1}$$

The correct volume between the horizontal plane with a height of 0 m and theoretical surface A is 653.19 m^3 and with theoretical surface B it is 1530.20 m^3. To evaluate the effect of the density, relative errors were calculated using the following formula:

$$r=\frac{V-V_{DEM}}{V}\cdot 100 \tag{2}$$

where r is the relative error in [%], V – the volume calculated using the integral calculus, V_{DEM} – the volume determined using the cross-sections from the DEM. The results obtained for both theoretical surfaces are shown in tables 1 and 2.

Table 1. Relative errors (%) for theoretical surface A

Density [mm]	Nearest neighbour	Inverse distance	Kriging
20	–	–	–
50	0.00	0.01	0.00
100	0.01	0.02	0.01
200	0.04	0.07	0.04
300	0.05	0.12	0.07
400	0.10	0.20	0.10
500	0.21	0.26	0.14
750	0.19	0.49	0.29
1000	0.11	0.76	0.41

Table 2. Relative errors (%) for theoretical surface B

Density [mm]	Nearest Neighbour	Inverse distance	Kriging
20	–	–	–
50	0.00	0.00	0.00
100	0.00	0.00	0.00
200	–0.01	0.01	0.01
300	0.01	0.02	0.01
400	–0.01	0.05	0.02
500	0.11	0.07	0.03
750	0.12	0.11	0.07
1000	0.25	0.35	0.13

From the above results it can be observed that the regular surfaces have high accuracy when calculating volumes, we have therefore focused on a further experiment, surfaces with an irregular shape.

3. RESULTS AND DISCUSSION

For practical measurement and subsequent analysis, two piles of earth in the shape of an irregular truncated cone were