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RELIEF MODELLING METHODS FOR TOPOGRAPHIC PLANS IN URBANIZED TERRITORIES

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Abstract. Relief modelling methods based on surveying data and GIS technologies for topographic plans creation in rapidly changing urbanised territories are analysed in the paper. 99 296 m^2 (9.9296 ha) area of Vilnius city, Antakalnis eldership, Šilėnų street was selected for the research. Geodetic measurements were performed by Trimble 5800 – Global Positioning System (GPS) receiver. Observation period – from the end of 2006 till the beginning of 2007. 568 height points were observed and used for digital relief modelling in this territory. Three methods were used for modelling: Kriging, Spline, and Inverse Distance Weighting (IDW). Depending on relief complexity, the suitability of these methods is analysed. The selection method was based on accuracy of standard deviation estimates.

Keywords: digital elevation model (DEM), relief modelling, modelling parameters, Kriging method, Spline method, IDW method, topographic plan.

1. Introduction

Preparation of topographical plans is a topical process and it is required for any kind of designing activities as well as construction of individual houses, living quarters, industry and trade objects. According to the regulations the design works can be performed on topographical plan not older than one year. Depending on the tasks of urbanistic and engineering development the material of large-scale topographic plans is relatively divided into two groups: topographic and engineer communications plans (Stankevičius, Paršeliūnas 2005). Technical regulations of Geodesy and cartography outline the rules for orders of topographic – engineering material and survey performance (GKTR 2.08.01:2000 "Constructional engineering surveying"; GKTR 2.01.01:1999 "Regulations for survey and mapping of underground communication networks"; GKTR 2.11.02:2000 for topographic plans preparation).

2. Goal of research

Most of surveyors are performing relief modelling for topographic plans especially in urbanized area by complex interpolation of point's heights – first using available software modelling method and completing manually. Spline or Kriging methods by GIS/CAD software are used most often without studying their characteristics and suitability for the area. Obvious errors are obtained, which often require new interpolation or completing it manually. Contours for neighbouring topographic plans are not corresponding quite often. This happens due to selecting different modelling methods. Therefore we aim to research and select best suitable modelling methods and their parameters for relief representation in complex territories.

3. Object of research

Creation of contour lines and 3D model of topographic plans at a scale of 1:500–1:5000 (Earth spherical shape is ignored, Geodesy and cartography act 2001) are analysed in this paper. Application of modelling methods for digital topographic plans preparation in rapidly changing urbanised territories from geodetic measurements and by using GIS technologies are analysed. 99 296 m^2 area of Vilnius city, Antakalnis eldership, Šilėnų street was selected for the research. This area includes boundaries of two garden communities. The analysed territory spreads up to 400 m to North-South direction and up to 300 m to East-West. Geodetic data are collected by GPS receiver Trimble 5800. Observation period: end of 2006 – beginning of 2007. 568 height points were observed during field measurements campaign. These height points are used for estimation of measurements accuracy control. According to regulations at least 4 height points per 10×10 m of smooth area must measured. If area is complex or urbanized, the number of measured height points must rise 3–4 times. Minimum number of height

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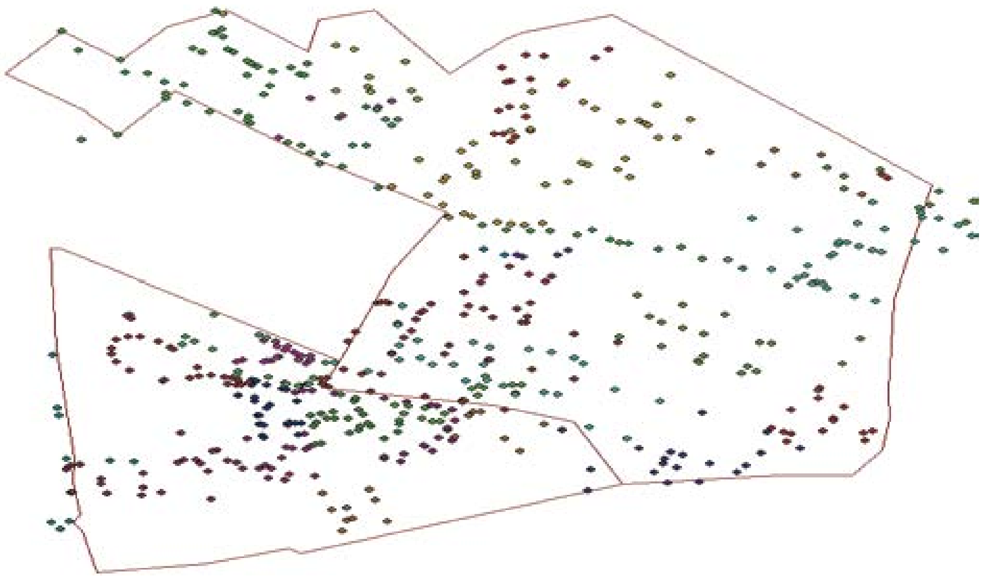

Fig. 1. Height points' location in a selected area:
♦ – points obtained by geodetic measurements; — – boundary of garden communities

points in the selected area should be at least 350–400 points. However, in the selected area with a prevailing smooth landscape, the slopes are present too as well as 7 ponds of 0.1660 ha total area. Moreover, this part of urban area is densely covered by summer houses, greenhouses, palings. Every road, pond and slope was measured for attempting the complete representation of typical terrain and landscape forms. The number of height points observed increased up to 568. Height points in the selected area are distributed unevenly (Fig. 1). Height points density and uneven location is resulted by objective natural and man-made obstructions (rivers, ponds, fences, roads, buildings, trees); surveyor's experience and qualification, land owners' refusal to collaborate (admit to territory); instruments breaks, and subjective (weather conditions: cold, rain); previously collected data usage (no accuracy, quality and suitability estimation; surveyor's tiredness, illness) factors.

Height points density and uneven location is resulted by objective (natural and man-made obstructions as rivers, ponds, fences, roads, buildings, trees); surveyor's experience and qualification, land owners refusal to collaborate (admit to territory); instruments breaks, and subjective (weather conditions as cold, rain), by previously collected data usage (no accuracy, quality and suitability estimation); surveyor's tiredness, illness factors.

4. Research

Digital relief model was created by ArcGis software with extensions *3D Analyst*, *Spatial Analyst* and *Geostatistical Analyst*. For relief modelling surface modelling geostatic tools were used, while modelling, parameters were selected manually. By changing values of parameters, effect of single parameters to relief models accuracy was investigated.

Circular variogram (Johnston *et a*l. 2001) was used for territory modelling by Kriging method in Antakalnis eldership of Vilnius (1). This type of variogram was accepted as best suited for Lithuanian territory modelling, based on a number of research publications (Kumetaitienė 2005):

$$\gamma(d;\theta)=\begin{cases}\dfrac{2\theta_s}{\pi}\left[\dfrac{\|d\|}{\theta_r}\sqrt{1-\left(\dfrac{\|d\|}{\theta_r}\right)^2}+\arcsin\dfrac{\|d\|}{\theta_r}\right] & \text{for } 0\le\|d\|\le\theta_r\\ \theta_s & \text{for } \theta_r<\|d\|,\end{cases} \quad (1)$$

where γ – the function of variogram; $d = (d_x, d_y)^T$; $\|d\|$ – the distance between points; $\theta_s \ge 0$ –the partial sill parameter; $\theta_r \ge 0$ –the range parameter.

One sector circle with an unidentified radius was decided to use after analysing the number of points, their distribution and relief features of the territory, because points are located quite thick. 568 height points were used for modelling. Mean distance between points in the analysed territory is 6 meters. Since radius defines territory, where existing height points are used for calculations, and the number of used neighbouring points is large, it is useless to limit the territory by the points not used for computations.

Digital relief models are created by simple Kriging method, using 6, 9, 12 and 15 neighbouring points of interpolation (Mitas 1988; Oliver 1990) (Table 1). Territory for the computations is defined by circle equal to the distance to the outermost point of interpolation.

Accuracy analysis of digital relief models was completed by calculating standard deviation σ according to the formula:

$$\sigma=\sqrt{\frac{(H_1-\overline{H})^2+(H_2-\overline{H})^2+\ldots+(H_n-\overline{H})^2}{n-1}}, \quad (2)$$

where n – the number of height points; H_i – height of point determined by circular variogram; $\overline{H}$ – height of a point by geodetic measurements.

It is important to select optimal dimensions of DEM cell for relief modelling. Terrain modelling and processing speed depends on cell dimensions. We have used 2×2 m cell dimensions, because data accuracy and modelling speed remains acceptable.

IDW method was used with different number of neighbouring (3, 6, 9, 12 and 15). Optimal weight value *(p)* is selected by software and equals 2 (Zevenbergen and Thorne 1987). Dimensions of rectangular network model's cell are 2×2 m. Models created by *IDW method* were tested with 568 height points.

Unknown point weight λ = 0,1 was used for surfaces created by *Tension and Regular spline methods (*Franke 1982; Heinrich 1994). The surface of a higher accuracy was obtained when tension spline method was used for modelling, while regular spline method did not fit to this territory (Table 1).

First order surface derivative was used in *tension spline method***.** The bigger value of power index, the less broken surface was obtained. The results indicate that it is important to select the method of surface modelling.

Thus the most suitable results and the minimal deviation from real surface are acceptable.

IDW method with selected 15 neighbouring points -idw_pow2_15 best suited for the analysed territory of Vilnius Antakalnis eldership (Fig. 2). Best results were obtained when 2×2 m cells dimensions of rectangular network models and weight value (p = 2) were used.

Estimates of standard deviation obtained by regular spline method are not presented in the diagram (Fig. 2), because when using this method the surface becomes too smooth what causes too large errors. Therefore regular spline method is not suitable for such a type of relief modelling (Table 1, Fig. 4).

The highest place of selected territory is in the North-West (Fig. 3). Surface is sinking towards the river in South-East. Most of the ponds are in the lowest part of a selected territory. Almost all lakes are at the lowest part of territory, exception – a few ponds in the centre of the North part.

The relief modelled with this method becomes too smooth and does not represent a real physic surface of territory.

The relief modelled with IDW and Kriging methods produce very similar DEM results (Figs 5, 6). But relief modelled by IDW method looks more realistic, especially in the areas near ponds, because even detailed features of analyzed territory are estimated. For example, there is a pathway in the Eastern part leading to the ponds, where there are no steep slopes. This form of relief was estimated with IDW method, but omitted with Kriging method.

DEM modelled with tension spline method produce general picture of selected territory, because only largest forms of relief are represented (Fig. 7).

Table 1. DEM accuracy relation with the used method of modelling

DEM method		Neighbouring points to include	Modelling parameters: Semivariogram	Modelling parameters: Weight	Standard deviation, σ, m
IDW	Idw_pow2_6	6	-	2	0,46
	Idw_pow2_9	9	-		0,30
	Idw_pow2_12	12	-		0,22
	Idw_pow2_15	15	-		0,18
Kriging	krig_apsk_6	6	Circular	-	0,47
	krig_apsk_9	9		-	0,31
	krig_apsk_12	12		-	0,24
	krig_apsk_15	15		-	0,19
Tension spline	spl_tens_6	6	-	0,1	0,54
	spl_tens_9	9	-		0,35
	spl_tens_12	12	-		0,25
	spl_tens_15	15	-		0,20
Regular spline	spl_reg_6	6	-	0,1	1,87
	spl_reg_9	9	-		1,40
	spl_reg_12	12	-		1,09
	spl_reg_51	15	-		0,89

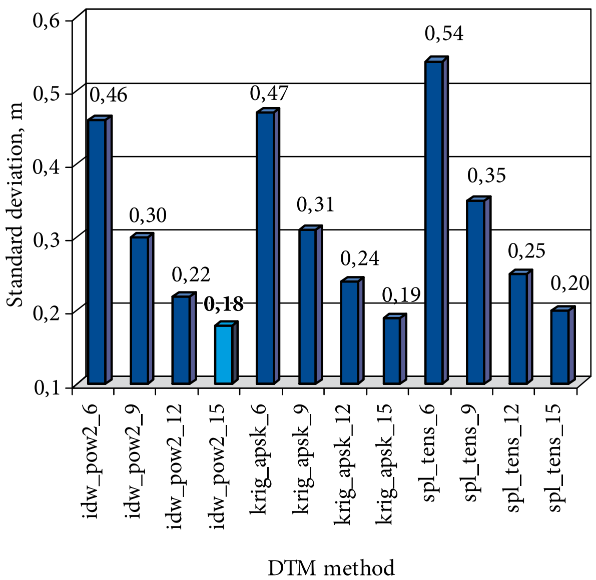

Fig. 2. Accuracy of DEM, using different methods

5. Conclusions

1. *ArcGIS* desktop with extensions *3D Analyst, Spatial Analyst and Geostatistical Analyst* was used as well as an available method of DEM constructions.

2. 99 296 m^2 area of Vilnius city, Antakalnis eldership, Šilėnų street was selected for research. This area was modelled by 3 methods: Kriging, Spline and IDW with option of selecting number neighbouring points and modelling parameters.

3. The most accurate DEM was obtained by modelling relief with IDW method. 15 neighbouring points were selected for interpolation, dimensions of rectangular network model's cell 2×2 m, value of weight p = 2 (standard deviation σ =0.18 m). The lowest accuracy obtained by modelling with tension spline method, where 6 neighbouring points were selected for interpolation, weight λ = 0.1 (σ = 0.54 m) was selected for point to be determined.

4. A surface modelled with regular spline method is obtained too smooth and with large estimation errors

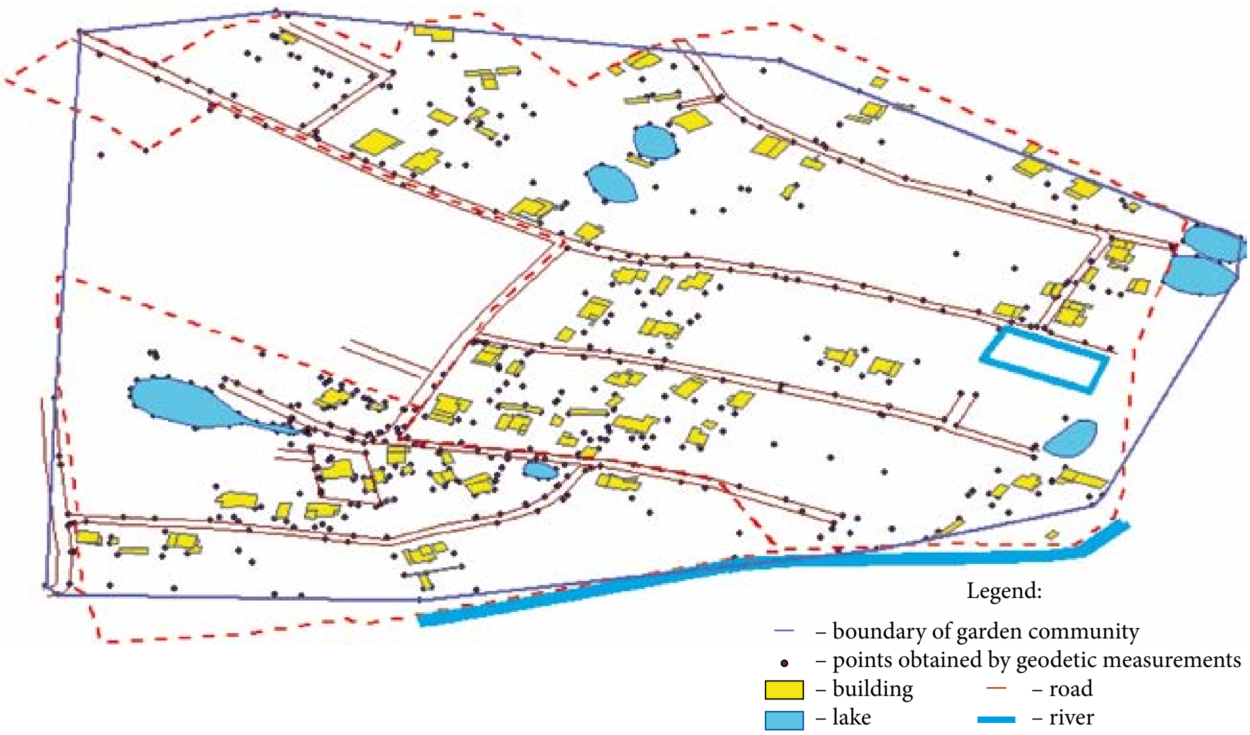

Fig. 3. Placement of main objects in a selected territory

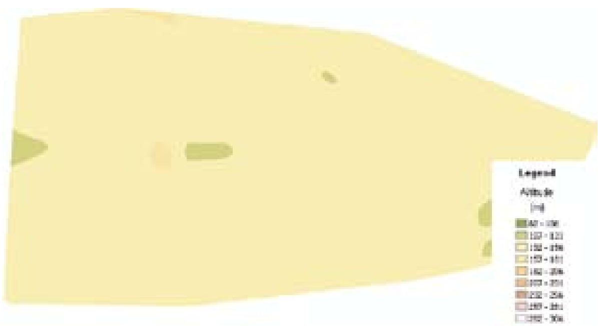

Fig. 4. DEM created by regularized spline method

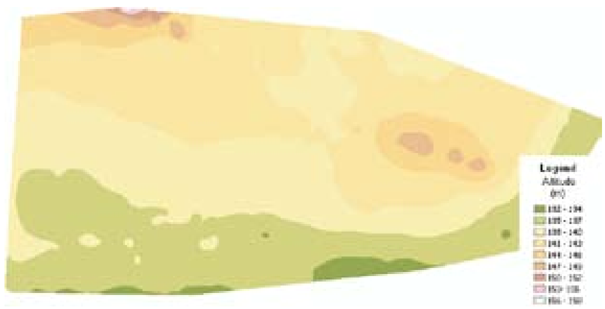

Fig. 6. DEM created by Kriging method

Fig. 5. DEM created by IDW method

Fig. 7. DEM created by tension spline method

(standard deviation σ estimate is over 0.89 m). This method is not suitable for such type of relief modelling.

5. Relief modelling by different methods for neighbouring territories produce not matching and sometimes opposite results. Moreover, a wrong selection of modelling method results in large errors of height. That's why it is important is to prepare recommendations to make easy a selection of suitable modelling method for a particular territory.

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