ERROR MAP OF LANDSLIDE MODEL RESULTING FROM THE ADOPTION OF DIFFERENT METHODS FOR THE DEFINITION OF DISPLACEMENT FIELD

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ABSTRACT

A vast area of landslide topped by a road, required tacheometric survey of marked points. As a result of repeated surveys the displacement vectors were obtained for each observed mark. Assuming that the points are a representation of spatial phenomenon, the map of movements of entire slope was carried out using two methodological approaches - the nearest neighbor (NN), in which weights to near lying observed points are much more important than to the more distant, and kriging, which describes the modeled phenomenon statistically. These approaches, like the most approximation techniques, base on the global nature of the phenomenon. In the meanwhile in not marked zone of described landslide the surface had been folded. In such cases the better is to take into account the aroused skeletal lines. The approximation techniques do not allow this. It was done using own algorithm TeMCA, which implements the method of cartographic cellular automata for surface modeling.
The purpose of this study is to analyze differences between various ways of description of slope movements defined by both conventional methods and to compare them to the results of the TeMCA method which should better comply the nature of the landslide. Analyses were performed on synthetic data in order to avoid the impact of survey errors. The results of modeling have been elaborated in a graphical form and the distances between the different models were calculated for all cells of the grid. Maps of errors have been generated by taking into account the visualization of model errors. The conclusions focus on errors of interpretation of the results obtained by considered methods of modeling.

1. INTRODUCTION

The results of displacement survey of points marked on the sliding surface can be presented numerically, in a form of the list of vector lengths, or graphically as a map of the vector field of displacements. In the case described above, it was considered that the projections of horizontal lines of displacement vectors have similar orientation, so the model was simplified to the form of scalars.
An illustration of such surface may be the digital raster model of slope movement, the counterpart of DTM. The literature contains many approaches to terrain modeling,

from simple interpolation, by polynomial approximation, with its various modifications, to the statistical methods [1, 2, 10]. Currently, research and implementation in the field of modeling focuses on combining the description of the nature of the global phenomenon with its local exceptions, with particular emphasis on various types of surface discontinuities and exclusions of a different nature [2, 4]. Whereas widely available software includes (i) inverse distance weighted (IDW) method, (ii) polynomials or splines and (iii) kriging [6].

The first is based on the assumption that the influence of height value of nearest reference point to the designated one is such significant that in its neighborhood the impact of other points is very low and decreases to zero proportionally to the distance. Between more distant points the model reaches average ground level. Such approach is essentially wrong and should not be implemented neither in land surface modeling nor its changes. Splines are prone to excessive smoothing of surface, and therefore require an additional tension over the frame of the reference points. Despite its many advantages, this method is not subjected to modifications which could take into account local discontinuities or turblences. The latter method (i.e. kriging) is mainly used for analyses and presentation of the phenomena of a statistical nature, therefore, although gives intuitively correct terrain representation it should not be applied to the deterministic problems. With a large number of variables it enables correct interpretation of statistical phenomena, but it requires the user's experience and knowledge of their nature. However, it is usually applied with the default parameters of the program [5, 6].

Very popular is also the nearest neighbor (NN) method, which in its trivial form is limited to the acquisition of heights of the nearest reference point, but in tessellation approach it determines the height of the interpolated point as an average weighted by the area of Tiessen polygons cut from the net of polygons lying closest to the surrounding reference points. In this form it much better describes terrain than IDW. In the analysis presented here, the latter approach was compared with the kriging method, assuming that the examined phenomenon of landslide may have a statistical form. Both models of the discussed landslide and results of their comparison, as well as observation that the modeled process is not homogenous, were the inspiration for the use of own method based on separate structural lines, and local relationships between directly adjacent pieces of land. This method uses the idea of cellular automata suited to the cartographic purposes [4, 6].

In the following results of landslide modeling both conventional methods are presented, then the own approach and the results of its use are described, and the differences of generated models of landslides are discussed.

2. THE NATURE OF THE PHENOMENON AND THE RESULTS OF ITS PRESENTATION

To show the problem described in this study a set of data presented in Figure 1 was considered. It contains 51 surveyed points, arranged in an unequal manner over monitored area of 210 by 240 m. The results of subtraction of heights obtained from the two measurements had been recorded as a set of scalar values of landslide. They vary in the range from 84 to 218 mm. The larger, upper part of landslide (left side of the figure) has the largest displacements, while in the central zone are variable displacements which have linear form (slightly skewed strip to the right of the central zone). Lower area

(right side of the figure) has also various displacement values, but with a much more gentle character. Unfavorable from the standpoint of displacement analysis is significant reduction of the number of test points in the middle zone of undulations. Perhaps these points have been destroyed by the irregularly moving ground. The task of the analysis is such presentation of the phenomenon that, despite the lack of surveyed data, will show its linear nature.

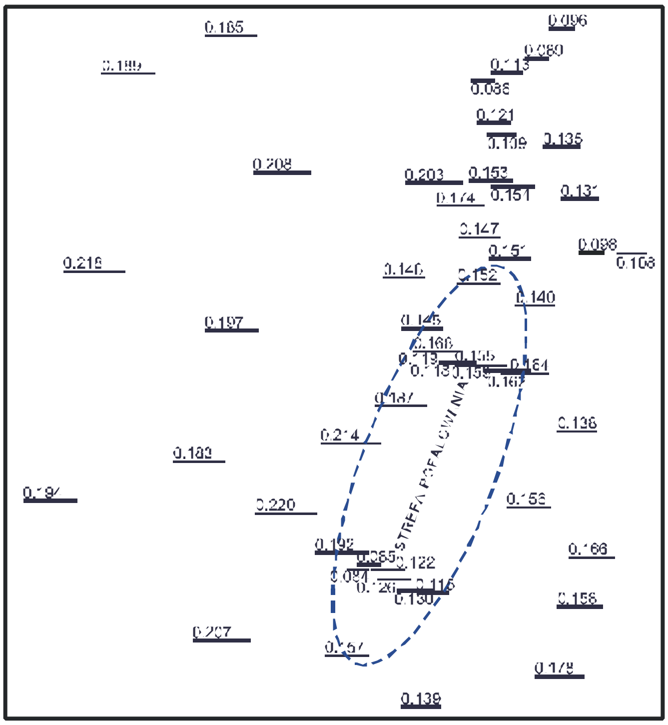
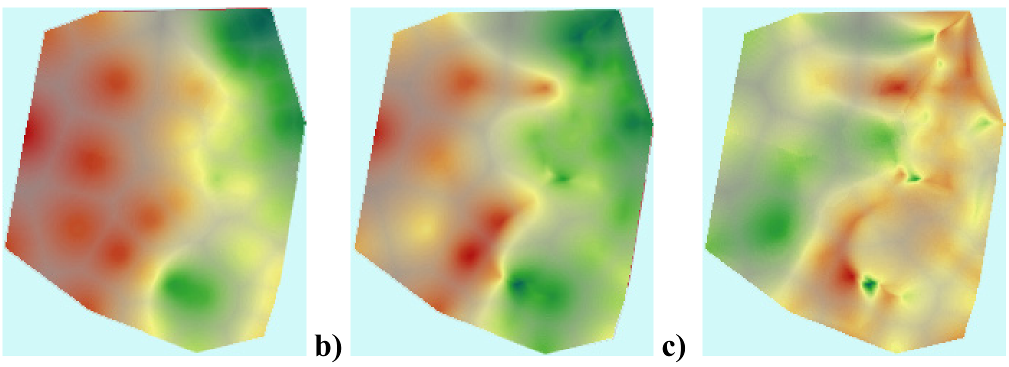


Fig. 1. The vector map of displacement of points on the landslide.

Figure 2 includes displacement maps obtained on the base of numerical models of landslides generated by classical methods: kriging (a) and nearest neighbor (b), and a map of differences between the two models (c). These differences are within ±56 mm what gives the standard deviation ±16 mm.



a) b) c)

Fig. 2. Raster map of landslides created by methods of kriging (a) and the nearest neighbor (b), and the map of differences between the two models (c). Red indicates the largest displacement and their diversity, green – the lowest ones, and decreased intensity of the color show less reliability of results.

In order to show the size of displacements the red-yellow-green color scale developed in the work [7]. Using this scale is to prove not only the spatial diversity of the phenomenon, but also an indication of the places where it is unusually unfavorable (deep red), where

insignificantly small (dark green), and - where is a transition zone (yellowish). Colors of this type are particularly useful in decision-making as it allows a person to make a quantitative assessment of the evaluation of the phenomenon. In addition, in the figure was presented the variation of color saturation (in the direction of gray) as the result of applying the algorithm for visualization of reliability assessment of the outputs. It adopts the assumption that uncertainty of the results increases with the distance from the test point [9], and the increasing uncertainty can be presented by "extinction" of a given color.

In assessing the differences of results of modeling, the attention draws darkest places indicating the greatest differences. They occur in the test points on the edge of the zone of undulations. Meanwhile, in the middle of this zone, due to the lack of points, mean values of displacement were calculated and the gray shades show less reliability of the model.

3. THE TeMCA METHOD SUPPORTING TERRAIN MODELING WITH DISCONTINUITIES

Given the considerable diversity of present forms in urban environment, it is necessary to use such modeling methods that include numerous structural lines and variability of forms occurring there in separate places. The method TOPOGRID used in the ArcView Spatial Analyst takes these lines into account in a limited range (regarding them as breaklines). The main method which allow defining edges (structural lines) base on the division into triangles in a manner derived from the method of TIN. Different edges may be indicated before or after the initial division into triangles according to the principles of TIN (conclusion of the circumcircle of the triangle), or the shortest distance between the points of steepest descent. The mesh of triangles can be later converted into a grid, but both forms are characterized by flat surfaces and edges along sides of triangles. This is unnatural image of the surface, so the area should be smoothed. Toward these conclusions comes the method TeMCA (Terrain Modeling with Cellular Automata), which is derived from cellular automata theory modified for cartographic applications.

The base of TeMCA method is interaction of automata with spatial data layers and the modeled layer, which commonly constitute the environment of automata [8]. These rules are shown in Figure 3. In the case of modeling of landslide the data layer consists of reference points and the resulting layer is created model.

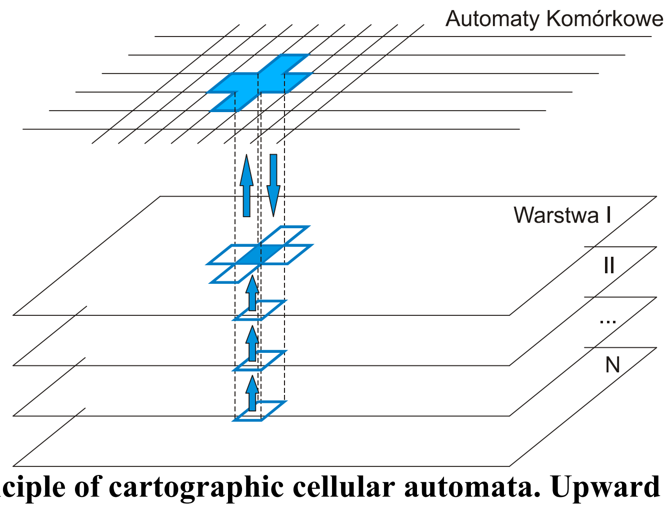


Fig. 3. The principle of cartographic cellular automata. Upward oriented arrows symbolize data collected by automata, and the downwards pointing arrow - their impact on the formed model.

The method has its computer implementation, so it can be easily used to make models of various surfaces. It has a number of tools to redefine the triangular division, to declare the type of lines (skeletal or brake lines), as well as determining the parameters of the modeling process. The task of modeling can be repeated many times along with accuracy assessment based on a set of control points or reference surfaces [5, 6].

4. THE LANDSLIDE MODEL CREATED BY TeMCA AND ITS COMPARISON WITH THE RESULTS OF APPROXIMATION METHODS

In the first stage of landslide modeling with TeMCA method the triangles generated automatically during initial division had been redefined. In order to demonstrate the heterogeneity of the phenomenon a number of elongated triangles was defined along the waves. Then automated interpolation has run. Effect of modeling is shown in Figure 4a. In the following figures were indicated differences between the TeMCA model and the models generated using methods of kriging (4b) and the nearest neighbor (4c). Reddish colors show differences of positive sign and greenish – negative one. The extreme differences do not exceed 50 mm.

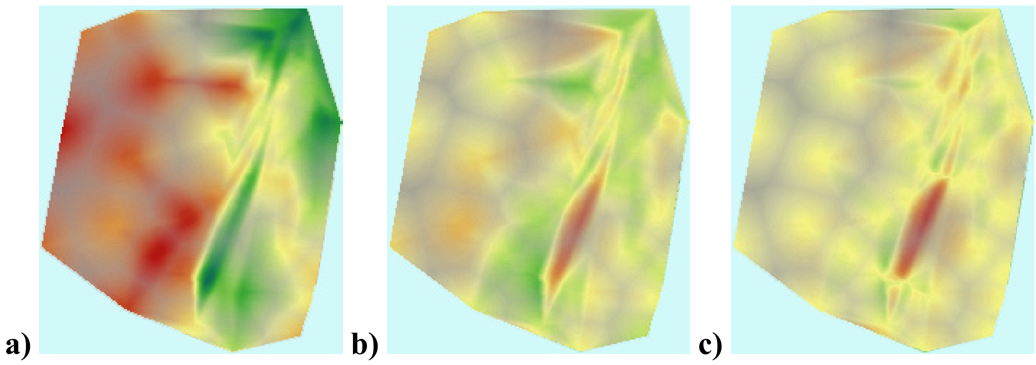


Figure 4. The result of modeling landslide using TeMCA method (a) and the differences from the models created with methods of kriging (b) and the nearest neighbor (c).

5. CONCLUSIONS

Assessing the results a widespread belief must be primarily confirmed that modeling of the phenomena associated with the surface of the terrain must take into account the structural lines [3, 4, 10]. This statement from its definition excludes deterministic or statistical approximation methods being readily in use. Assuming, however, smooth nature of the phenomenon is impossible to obtain similar resulting models made by various methods. Obtained discrepancies can sometimes be very large (Fig. 2c).

The proposed TeMCA method creates a model on the frame defined by the operator [4, 5, 6], so that it gives results taking into account discontinuity lines identified at site (Fig. 4a). Differences between this model and the two previously discussed, visible in Figures 4 b) and c) are primarily in the folded region. With the development of the described method one can expect a much more accurate modeling of landslide than using methods available in GIS software.

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