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Classification of Terrain Concave and Convex Landform Units by using TIN

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Abstract— **The concave and convex landform units are significant components of terrain surface. However, the properties of two landform units are traditionally calculated from the Grid-DEM, which is usually the secondary product of TIN-DEM. Therefore, the use of TIN can reduce the uncertainty caused by this conversion. In this study, we proposed a qualitative method based on TIN DEM data to classify terrain concave and convex landform units. By judging the property of each node and then setting the Voronoi region in a TIN, the concave and convex areas will be determined. The proposed method was used and validated in a mathematical Gaussian surface and two small catchments in this study. Results show that the proposed method has a high correctness for classification of concave and convex landform units. And our method is also suitable for the constrained and non-constrained TIN. In addition, the proposed method should be an extension in digital terrain analysis based on TIN.**

I. Introduction

The terrain surface of concavity and convexity are fundamental concepts in geomorphology. Generally speaking, the concave and convex landform units control the direction of flow, the transport of materials, and the deposition of soil [1] [2]. The calculation of concavity and convexity is traditionally based on Grid-DEM by using terrain curvature. Nowadays, the production modes of Grid-DEM have been rapidly developed, such as the point clouds method [3]. Obtaining point clouds from Lidar or UAVs becomes more and more convenient. The triangulated irregular network (TIN) usually becomes the bridge from point clouds to Grid-DEM [4]. However, this conversion has uncertain problem of interpolation method, which may lead to unforeseeable errors in application [5]. On the other hand, the simplification of many high resolution (5m or higher) Grid-DEM is necessary for the coarser analytical scale [6], especially the classification of concavity and convexity. There are many studies on extracting terrain feature information from Grid- DEM to reconstruct TIN [7], which is helpful for large scale research. To reduce the uncertainty from point clouds to Grid-DEM and improve the generalization in scale transformation, a group of new methods based on TIN should be explored.

Currently, the terrain analysis methods based on TIN have been discussed for decades. Several terrain derivatives (like slope and aspect), flow direction algorithms, visibility analysis, and dynamic hydrology models can be well calculated based on TIN [8] [9] [10]. In addition, the extraction of morphological information from TIN has been exploring as well. Falcideeno and Spagunolo (1991) pointed out that the morphological type of an edge can be determined by its adjacent two triangles [11]. However, they then decided the morphological type of a triangle by its labeled edges, which was inappropriate in some special cases (like the boundary of TIN). Van Kreveld (1996) defined the plane and profile curvature for each node in a TIN, and proposed the Voronoi diagram which can be used as terrain partition [12]. Nevertheless, this method is unable to effectively classify terrain concave and convex landform units. In fact, the mentioned methods did not make use of the positional relationship between a node and its adjacent nodes. The relationship should be explored and used in the classification of terrain concave and convex landform units. In this study, we firstly give a concave or convex label to each node of a TIN by taking the relationship between a node and its adjacent nodes into account. Then, the Voronoi diagram is applied to these labeled nodes to divide the terrain surface.

II. Data and Methodology

A. Data

In this work, three study areas are selected to validate the proposed method: a simulated mathematical Gaussian surface and two small catchments. The Gaussian Surface is defined by the formula [13] as follows:

$$z = 100A[1-(\frac{x}{m})^2]e^{-(\frac{x}{m})^2-(\frac{y}{n}+1)^2} - 100Ce^{-(\frac{x}{m}+1)^2-(\frac{y}{n})^2} - 100B[0.2(\frac{x}{m})-(\frac{x}{m})^3-(\frac{y}{n})^5]e^{-(\frac{x}{m})^2-(\frac{y}{n})^2} \quad (1)$$

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where *A*, *B*, and *C* are terrain relief parameters; and m and n are range control parameters. These parameters are set as *A* = 3, *B* = 10, *C* = 1/3, *m* = 500, *n* = 500 with 5 m of resolution (Figure 1(a)). The first small catchment is Qiaogou (37°34′11″ N, 110°16′53″ E) with 0.45 km^2 area (Figure 1(b)). The point clouds data generated by UAVs is used to construct TIN to validate our method on the non-constrained TIN. Then, the second larger catchment Liujiagou (Figure 1(c)) (37°36′48″ N, 110°17′20″ E) is 6.9 km^2 with a loess-hill landform. Grid-DEM data with 5 m resolution in this area will be convert into TIN with different *z-tolerance*, and the vertices of stream lines will be participated in the construction of TIN [14]. The two catchments are located in the north of Suide County, Shaanxi Province, China.

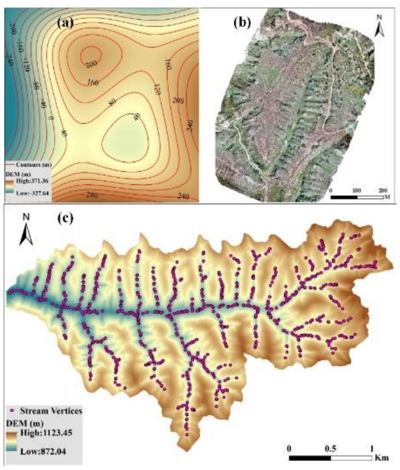

Figure 1. Study areas. (a) Gaussian surface, (b) image of Qiaogou from the UAVs and (c) small catchment Liujiawan with the stream lines vertices.

B. Method

A TIN is consisted of nodes, edges and triangles. Except the nodes on the boundary of the TIN, there are at least three nodes around a center node. These around nodes are called adjacent nodes of the center node. For each center node, its convexity or concavity is certain. As we all know, three points in space can form a plane. The positional relationship between a center node and a plane is above, below, or within (e.g. the center node is above a plane). Without loss of generality, the case of a center node with four adjacent nodes was selected as an example to represent all situations. The four space points can generate four different planes at most. Considering all the cases, the positional relationships between the center node and the four space planes can be summarized in Table 1 and Figure 2.

There is a special case in Figure 2(g), the center node is a saddle point in theory. However, we still regard it as a concave node. Then, we can set a series of simple judgment principles for a center node with more adjacent nodes.

(1) If the number of "below" is greater than or equal to the number of "above", the center node is a concave node.

(2) If the number of "below" is less the number of "above", the center node is a convex node.

(3) If the center node is in all the planes, it is a flat node.

Finally, each labeled node can generate a Voronoi region with the same label.

Table 1 Positional relationship between center node and four planes (e.g. the center node is above the Plane BCE).

Positional Relationship	Plane BCE	Plane BCD	Plane BDE	Plane CDE	Center Node Property
(a)	Below	Below	Below	Below	Concavity
(b)	In	Below	Below	Below	Concavity
(c)	In	In	Below	Below	Concavity
(d)	Above	Above	Above	Above	Convexity
(e)	In	Above	Above	Above	Convexity
(f)	In	In	Above	Above	Convexity
(g)	Below	Below	Above	Above	Saddle
(h)	In	In	In	In	Flat

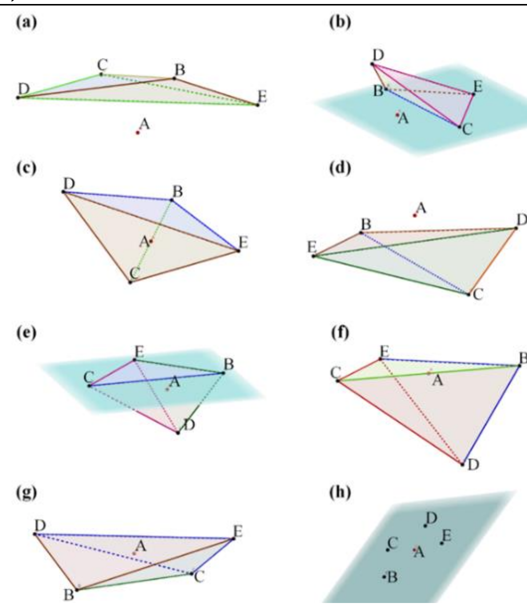

Figure 2. Eight cases for positional relationship between the center node and four adjacent nodes. Each case corresponds with a column in the table 1.

III. Results and Conclusion

A. Comparison with the surface curvature

To assess the accuracy of our method, we set the surface curvature results as the reference data [15]. If the surface curvature value of a grid is less than or equal to zero, this grid set as concave, otherwise as convex. The *z-tolerance* is 0 m in the conversion from Grid-DEM to TIN, which means all the grid points are participated in building of TIN (The surface curvature and Grid-DEM to TIN tools can be found in ArcMap 10.2). The Gaussian surface results are displayed with contours (Figure 3(a) and (b)). The result of our method is the same as the surface curvature result in the majority area of the Gaussian surface. And some differences mainly belong to the saddle region, which may come from the conversion of Grid-DEM to TIN. In addition, the comparison results in real landform of Liujiawan are also displayed (Figure 4 (a) and (b)). Obviously, both results are almost the same. The comparisons between results of surface curvature and our method on Gaussian surface and real landform show that our method can provide a credible enough classification of terrain concave or convex landform unit. The correctness of our method can be validated to some extent.

B. Classificaton for contrained and non-contrained TIN

TINs can be divided into constrained and non-constrained TIN. In this section, we explore the classification capacity of our method on both two types of TINs.

The TINs are firstly generated from the Grid-DEM data in Liujiawan by *z-tolerance* method, and then constrained by the stream vertexes. With the *z-tolerance* increasing, the terrain will be generalized and the analytical scale will be coarser. In the small catchment Liujiawan, we select 5 m, and 15 m as two *z-tolerances* parameters. Although the terrain information was sharply reduced, the streamlines vertices still control the valley areas. The results are displayed in Figure 5 and overlaid with hill shading as well. Under such scale, the positive terrain can be regarded as convex terrain, while negative terrain is concave terrain. Our method can provide a reasonable concave and convex classification of terrain on the constrained TIN.

On the other hand, the non-constrained TIN is produced from the points clouds data in Qiaogou. The classification result is displayed in Figure 6. Due to the point clouds data is relatively density, the micro terrain information can be well described, such as the agricultural terraces, the steep scarp in the bottom of the valley, the artificial path, the ridges, and the rills on the hill slope. Meanwhile, the concavity and convexity classification of these terrain elements by our method is good enough to a certain extent.

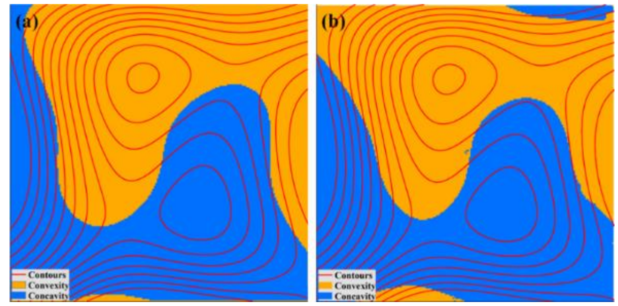

Figure 3. Results in Gaussian surface. (a) Classification by surface curvature based on Grid-DEM. (b) Classification by our method based on TIN with 0 m *z-tolerance*.

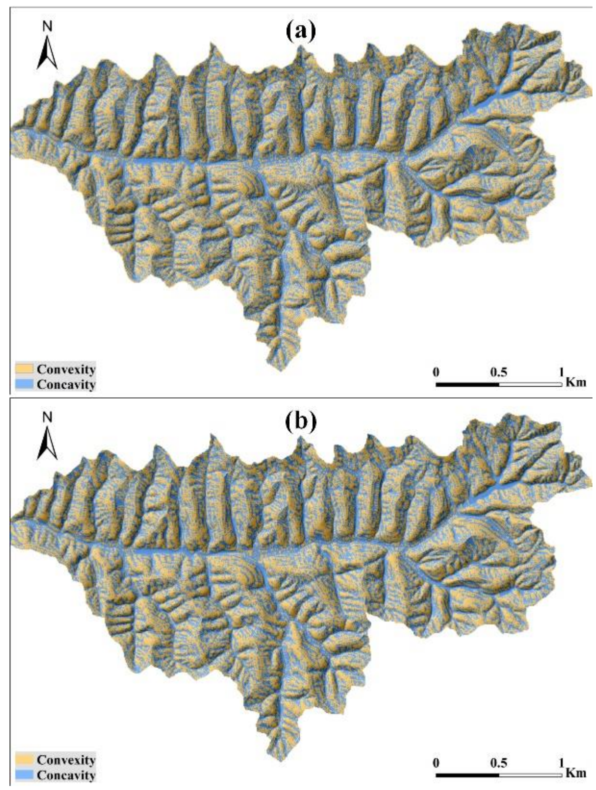

Figure 4. Results in Liujiawan. (a) Classification by surface curvature based on Grid-DEM. (b) Classification by our method based on TIN with 0 m *z-tolerance*.

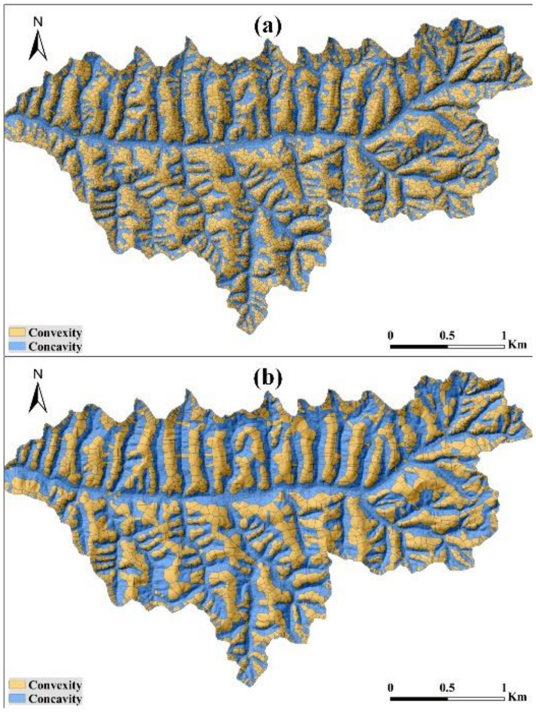

Figure 5. Results of constrained TINs that from Grid-DEM with different z-tolerance. (a) TIN with 5 m *z-tolerance*. (b) TIN with 15 m *z-tolerance*.

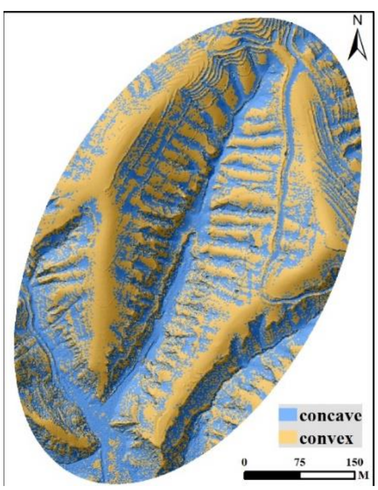

Figure 6. Result of non-constrained TIN that generated from point cloud.

Conclusion and Future Work

In this study, we proposed a qualitative method to classify the terrain concave and convex landform unit. By judging the positional relationship between the center node and its adjacent nodes, the property of the center node was determined. Then the terrain was divided by the Voronoi region of each node. The results obtained from our method were compared with the surface curvature method, which shows the correctness of our method. Our method also displays the ability of processing the constrained and non-constrained TINs.

Comparing with the kinds of curvature calculation methods based on Grid-DEM, our method is still inadequate. The future work is to explore the quantitative calculation method of concavity and convexity based on TIN.

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