SIMILARITY OF TERRAIN SKELETONS MEASURED BY TOPOLOGICAL INDICES AND SPATIAL ORIENTATION INFORMATION

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KEY WORDS: DEM, Extraction, Measurement, Fuzzy logic, Geomorphology, Pattern Recognition

ABSTRACT:

Terrain skeletons have played a key role in survey and mapping, hydrological applications, military applications, generalization studies, determination of political borders, discovery of the steepest slope path and so on. Based on DEM, the terrain skeleton can be extracted effectively. At the same time, the pattern recognition widely used in the fingerprint matching, script recognition and security authentication. From the viewpoint of pattern recognition, the terrain skeletons are the characteristics of terrain. How to measure the similarity of skeletons and promote the pattern recognition skeletons based is one of the urgent research fields. In fields of spatial analyst, spatial object can be interpreted at least by topology relationship and spatial orientation. In this paper, the aim is to construct a set of methods combination topology indices and spatial orientation. The result shows that topology indices showing some advantages in portray the geomorphologic characteristics and the Loess Liang has more prominent orientation than Loess Mao.

1. INTRODUCTION

Terrain skeletons, among the most significant elements of topographical maps, are the valley lines that connect the deepest points of valleys, and the ridge lines that connect the highest points of ridges. In order to obtain correct and enough information of landforms from a topographical map, skeletons have to be considered and portrayed together with contours. Their extraction has a great importance in the different areas. They can be gathered from contours, digital elevation models (DEMs) or other data sources. Extraction of Terrain skeletons has a great importance in the different areas where topographical maps are used such as hydrological applications, military applications, generalization studies, determination of political borders, discovery of the steepest slope path for hiking and mountain climbing, relief representation and determination of soil or rock type of a land.

Since skeletons indeed reflect the characteristics of terrain and the contour lines bend precisely on them, the skeletons can be regarded as one of the important marks of terrain. And then it becomes an interesting question, how to measure the difference of skeletons? In other words, is there some relationship between skeletons and geomorphologic types, just like the thing that has been doing in the fields of biological recognition? In order to compare the similarity and dissimilarity in different geomorphologic areas, a study on similarity measurement was investigated.

Up to now, many researchers have done plenty of related work on the extraction of terrain skeletons. Peucker and Douglas(1975), Toriwaki(1978), Lee(1992) and Wood(1996) have done many constructive work on the extraction skeletons. Yeoli(1984) defined some rules that should be used when linking the feature points into skeletons. While because of some fundamental properties of landform features, say vagueness and scale-dependence (Fisher, 2004), there are still many work should be done on the uncertainties of extraction, threshold conditions and fuzziness of multi-scale landform features (Fisher, 2004). And in the study of skeletons, Werner(1994) did much work on the interdependence of valley and ridge. Due the Werner's study, the relationship between valley and ridge can be regarded as some kind of dual graph, which implies the ridgeline or valley can reveal the main terrain characteristics well individually. And in the following part of this paper, the skeletons are limited into ridgelines, based on which the topology indices and spatial orientation were calculated.

When referring to landform classification, methods in existence mainly depend on the terrain parameters and their combinations (Tang Guoan et al, 2006), including elevation, mean elevation, slope, and gullies density, and so on. Those methods used mainly depended on the large account of statistical information on the terrain, without any feature or skeletons extraction. When terrain skeletons gotten, those feature lines can be regarded as certain kind of graph, or network according to graph theory. The complexity of feature lines indicates the difference of landform, which correspondingly can be used to measure the similarity of landforms. In order to measure the difference of topological relationship among different landform, some topological index (Niao Qiang, 2001), including node adjacency index, connectivity index, and extended ones.

While as a matter of fact, the spatial orientation of skeletons is one kind of important information when trying to acquire the spatial structure. In research reported recently, spatial orienta-

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tion became one of the hotspot fields in spatial analysis and related issues (Ding Hong, 2004). In the following part, the discussion will be based on the topology indices combination with spatial orientation information used to measure the similarity of skeletons.

2. METHODS

2.1 Extraction methods

In the section of skeletons extraction, the main steps can be described as follows.

First step is the choice of appropriate scale.

According to the definition, ridgelines are long narrow chains of hills or mountains and channel lines (valley) are elongated lowland between ranges of mountains, hills, or other uplands. The aim of choice of appropriate scale is to decide where can be classified into convex relief and what is the extent of positive relief.

Let $f(i,j)$ be the elevation of point (i,j) and n, the window size, there are some notations about the landform context as follows.

$$\overline{f}(i,j)=\frac{\sum_{m=-lag}^{lag}\sum_{n=-lag}^{lag} f(x_{i+m},y_{j+n})}{n^2} \qquad (1)$$

$$lag=(w-1)/2,\ w=3,5,7,\ldots,n \qquad (2)$$

$$sign(i,j)=\begin{cases}1,\ f(i,j)-\overline{f}(i,j)>0, convex\\ 0,\ f(i,j)-\overline{f}(i,j)<0, concave\end{cases} \qquad (3)$$

Let A_k be the mean areas of positive relief of the landform with the window size $k\times k$, A_{k+1} with $(k+1)\times(k+1)$ and A be the whole area of the study area. If the mean area A_{k+1} satisfies the formula (4), the mean area is stable and choice of scale for analysis has been gotten.

$$\frac{|A_{k+1}-A_K|}{A}\le\frac{0.01}{100} \qquad (4)$$

And second step is to bridge the gap between the accumulation threshold and positive relief.

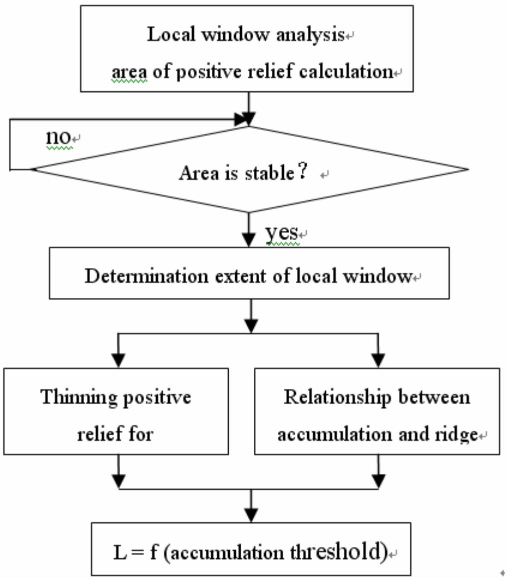


Figure 1 bridging the gap between accumulation threshold and ridgelines length

Given positive relief, it should be clear how to determine accumulation threshold to match the positive relief. When the accumulation threshold was choose, the watershed divides can be extracted, when overplayed with positive relief the ridgeline can be extracted.

And the last step is to check and correct the blemishes on the ridgelines according to different demands.

2.2 Quantitative measurement methods

As mentioned above, this section will concentrate on how to measure the similarity based on adjacency index, connectivity index, the extended topology index and spatial orientation information.

According to graph theory (Marchette, 2004), graphs, degree of vertex, adjacent index of edges and extended topological index can be defined as follows.

The graph is a fundamental structure for analysis in a wide range of discrete mathematics. A graph G is a pair $G=(V,E)$ for which the non-empty (usually finite) vertex set is $V=V(G)=\{v_1,\ldots,v_n\}$ and edge set $E=E(G)$ is a collection of unordered pairs of vertices (v_i,v_j). Normally we disallow edges from a vertex to itself (loops); $(v,v)\notin E$ for any $v\in V$. $n=|V|$ is called the order of graph and $|E|$ is called the size of the graph. If $(v_i,v_j)\in E$, two vertices v_i and v_j are said to be adjacent. A graph can be represented in a number of different ways. An equivalent representation is as an adjacency matrix A_G, which encodes the edges as entries in a matrix whose rows and columns correspond to the vertex set. That is, A_G is an $n\times n$ binary matrix with

$$a_{ij}=\begin{cases}1, v_iv_j\in E(G)\\ 0, else\end{cases} \qquad (5)$$

Where n is the order of the graph G .

The degree of a vertex v is the number of edges incident on the vertex; that is,

$$d(v) = \left|\{w \mid vw \in E(G)\}\right| \tag{6}$$

The adjacency index of edges can be defined as follows.

$$A_E = \sum_{1}^{|E|} \left(v_i v_j\right)^{-\frac{1}{2}} \tag{7}$$

According to the entropy theory, the entropy of graph can be defined in two steps.

Firs step, the function for importance degree of vertex is defined.

$$I_i = d_i \Big/ \sum_{i=1}^{|V|} d_i \tag{8}$$

And the second step, entropy of the graph can be given as follows.

$$E_G = -\sum_{i=1}^{|V|} I_i \ln I_i \tag{9}$$

The connectivity index can be defined as follows.

$$c = |E| \Big/ \frac{1}{2} n(n-1) \tag{10}$$

As one kind of spatial object, terrain skeletons also can be described by spatial orientation. When investigating the contour map of Loess Liang (Loess Ridge, Liang in Chinese) area, it can be acquired that the ridge lines show obvious structure information, namely spatial orientation information, while the ridge lines along the Loess Mao (Loess Hillock, Mao in Chinese) does not. With the aim to measure the differences mentioned above, the spatial orientation was divided into four groups, every of which represent the range of azimuth angle $(0°,45°) \cup (180°,225°)$, $(45°,90°) \cup (225°,270°)$, $(90°,135°) \cup (270°,315°)$ and $(135°,180°) \cup (315°,360°)$ respectively. In different geomorphologic regions, the frequency distribution is different. Then according to the entropy definition, the spatial orientation entropy can be calculated as follows:

$$E_{orientation} = \sum_{i=1}^{4} p_i \ln p_i \tag{11}$$

$$p_i = c_i \Big/ \sum_{i=1}^{4} c_i \tag{12}$$

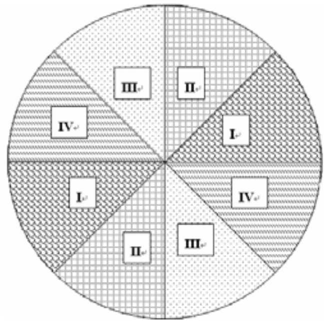


Figure 2 the spatial orientation grouping

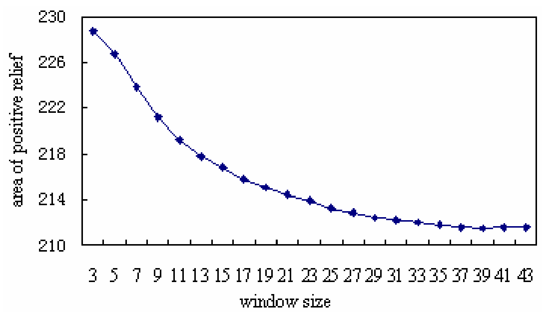
3. DATA AND MATERIAL

The typical characteristic of topography in Shaanxi is the topographic diversity. There are more than three typical geomorphologic types, including mountain, hill, plain and plateau in Shaanxi. The Qinling Mountain and Bei Mountain separate the whole area into three natural regions in a general state. The Loess Plateau is located in the north part of Shaanxi, Guanzhong Plain in the middle and Qinling and Ba Mountain in the south. Among those regions, Loess Plateau is the most severe soil and water loss area in the world because of the special geographic landscape, soil and climatic conditions, and long history of human activity, which has produced many peculiar geomorphologies, say Loess Yuan (Loess Plateau, Yuan in Chinese), Loess Liang (Loess Ridge, Liang in Chinese), and Loess Mao (Loess Hillock, Mao in Chinese) (Tang Guoan, 2005).

The data used in the experiment is 25m resolution DEM in Shaanxi province, produced by State Bureau of Surveying and Mapping. In the experiment, several typical areas were chosen, including Daba Mountain, Loess Mao and Loess Liang.

4. RESULT AND DISCUSSION

Area of positive relief in the eight areas has been shown in Figure 3 by different window size. The area of positive relief decreases correspondingly in eight areas when the window enlarged. The area of positive relief in No. 1 decreases the sharpest from window size 3×3 to 15×15 , after which the decreasing tendency becomes lowly. When the window size arrives at 39×39 , the area of positive relief becomes relatively constant. But when the window continues enlarging to 43×43 , the area of positive relief becomes bigger, which means window 39×39 can be regarded as the turning point. So the biggest window used in No. 1 is window 39×39 . And in other two areas, the biggest windows reach 31×31 and 27×27 .



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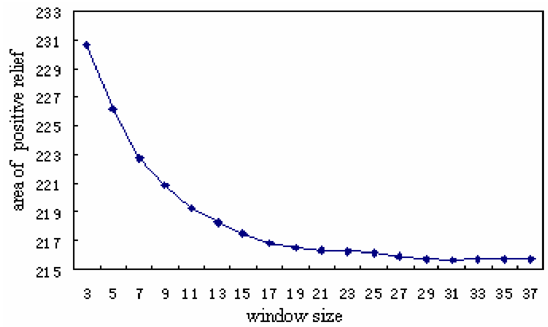

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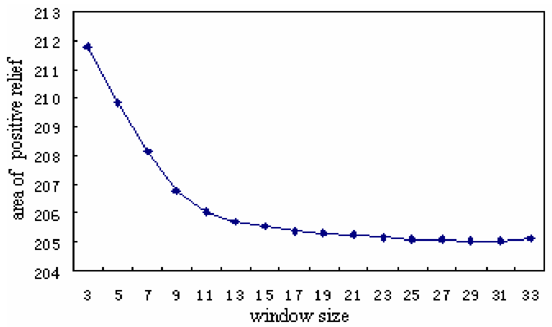

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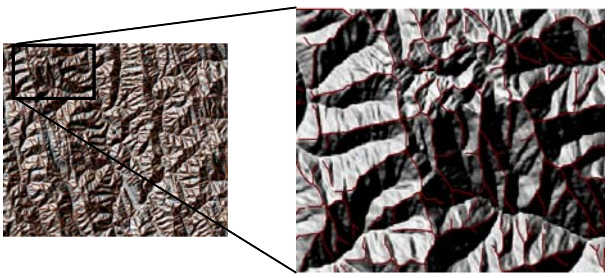
Figure 3 the local window size and positive relief

When given the positive relief, through morphologic operation, such as thin, the simulated ridgelines can be obtained, which are not as accurate as the true ridgeline which should have distributed on the highest part of the uplands, hills or mountains. While the simulated ridgelines can aid to investigate what is the relationship between the accumulation threshold and the length of ridgelines. At last the accurate ridgelines could be extracted by appropriate accumulation threshold and the watershed divides which are shown as follows.



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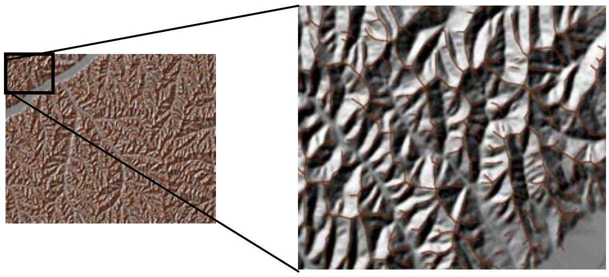

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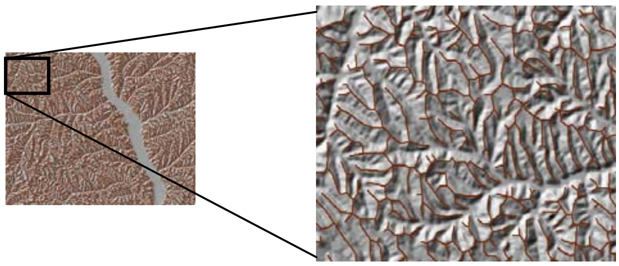

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Figure 4 the ridgelines

With the quantitative measurement methods mentioned before, the similarity among Daba Mount, Loess Liang and Loess Mao can be measure as the followed table.

	Adjacency index	Adjacency entropy	Graphs density	Connectivity index	Orientation entropy
Daba Mount	920	7.16	0.44	0.35%	1.038
Loess Liang	1073	7.86	0.74	0.20%	1.034
Loess Mao	3409	8.76	2.00	0.08%	1.368

Table 1 the topology index and entropy of spatial orientation

Form the table, it can be leant that the topology indices and entropy of orientation can reveal the difference among the three areas. And it is interesting that from the table, it seems like that the loess Liang is more analogical with Data Mount than Loess Mao, which is thanks to the typical characteristics of Loess Liang used in the experiment. The Loess Liang is nearly a micro mountain with all ridgelines connecting together well. It also demonstrates that Loess Liang has the more prominent spatial orientation information than Loess Mao.

When compared the topography indices with other fundamental information among the three areas, it can be learnt that the connectivity index shows strong positive relativity with gully density, while other parameters are not.

	Mean elevation(m)	Max elevation(m)	area(k ㎡)	Gully density (km/k ㎡)
Data Mount	826	2403	455.29	2
Loess Liang	1037	1445	425.72	4.4
Loess Mao	836	1204	418.68	5.2

Table 2 the fundamental information about the areas

In the discussion of entropy of spatial orientation, it should be noticed that the orientation entropy maybe different when the spatial orientation divided into different groups, which shows some uncertainty among the calculation. How to group the spatial orientation to obtain better result is an unsolved job.

5. CONCLUSION

The study shows that the Loess Liang is more similar with Data Mountain than Loess Mao when using the spatial oreintation information. The study also shows there is bigger density of skeletons in Loess Plateau areas than mountainous area, while bigger connectivity indices and smaller entropy index in mountain area than others. In Loess Mao area, the skeleton density is the biggest among the areas with the biggest entropy index and inapparent spatial information, which shows that Loess Mao is more complex and fragmentized than other area because of soil erosion.

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