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Ridge Detection with the Steepest Ascent Method

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Abstract

We propose a new method to detect ridges from digital elevation map (DEM) data. We call it "the steepest ascent method" which is based on steepest ascent lines obtained by selecting the maximum inclined direction from eight neighbors. Then ridge lines are extracted by their steepest ascent lines on a surface. In this paper it is shown that our method is able to detect ridge lines sharply. Besides we claim that our algorithm is simple and suitable for huge area such as the entire area of Japan. Finally, we give the ridge detected terrain map of the entire area of Japan and Korea by applying "the steepest ascent method".

Keywords: ridge detection, the drop of water principle ;

1. Introduction

It is very important to sharpen features such as ridges for the effective displaying of 3D terrain maps. This paper deals with *ridge detection* methods to accurately display huge terrain maps with their features.

First we note the discrete Laplace transform method which is one of well-known methods to extract their features. This method is to extract mesh ridges and valleys by evaluating the second order difference so-called "the discrete Laplacian".

Next, we recall another method called "the steepest descent line method" given by Yokoyama et al. in [3]. Steepest descent lines are similar to ones by *the drop of water principle* (*cf.* [4]), that is, they are obtained by selecting the minimum inclined direction from eight neighbors. Then ridge lines are extracted by their steepest descent lines on a surface.

However, these two methods are insufficient to sharpen features such as ridges. In this paper, we propose a new ridge detection method which is a modification of the steepest descent line method. We call it "the steepest ascent method". In this paper it is shown that our method is able to sharply detect ridge lines in 3D terrain maps. Besides we claim that our algorithm is simple and suitable for huge area such as the entire area of Japan. Finally, we give the

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ridge detected terrain map of the entire area of Japan and Korea by applying our method.

In Section 3, we provide an algorithm for a ridge detection method called the steepest ascent method. Furthermore, we compare the steepest ascent method with the discrete Laplace transform method in certain areas and with several threshold values. In Section 4, we show a process of ridge detected 3D terrain maps from digital elevation map (DEM) data. By applying the process we generate the ridge detected entire Japan terrain map about 4.5 x 10^7 cells and Korea map about 3.3 x 10^7 cells. Finally, in Section 5 we draw the main conclusions.

2. Relatedwork

2.1. The Discrete Laplace Transform

First we recall the discrete Laplace transform method (D.L.T. method). This method evaluates the discrete Laplacian, $\Delta f(m, n)$, defined as follows

$$\Delta f(m,n) \equiv f(m-1,n)+f(m+1,n)+f(m,n-1)+f(m,n+1)-4f(m,n), \tag{2.1}$$

in which $f(m, n)$ is the elevation value at the coordinate (m, n).

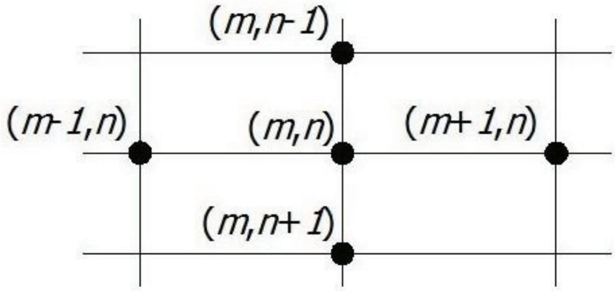

Figure 1. Elevation value is given at each of coordinates.

Precisely, when a negative threshold value h_0 is given, if $\Delta f(m, n)$ is less than or equal to h_0 then we regard the cell on (m, n) as a part of ridge lines. After the evaluations with (2.1) for a given 3D terrain map, the ridge detected 3D terrain map by D.L.T. method is generated.

2.2. The Drop of Water Principle

Yokoyama et al. [3] provided a system for recognizing ridges, valleys, and contours from landform maps. The extraction of ridges is executed as follows: First, multiply each of all elevation values by -1 to reverse a given 3D terrain map. And then this method extracts ridge lines by applying the drop of water principle for reversed map. We note that the drop of water principle provides a separating set of points from which a drop of water can flow down. (See [4].) As the results, the ridge detected 3D terrain map by the steepest descent line method is generated.

2.3. Ridges and Valleys in the Image

We remark that Lopez et al. [1] reviewed the formalization of the intuitive notion of ridge/valley principal characterizations and proposed a new one. Ohtake et al. [2] proposed a simple and effective method for detecting view- and scale-independent ridge-valley lines defined via first- and second-order curvature derivatives on shapes approximated by dense triangle meshes.

3. The Steepest Ascent Method

3.1. Algorithm

In this section we propose a new method to detect ridges from DEM data. We call it "the steepest ascent method" which is based on steepest ascent lines obtained by selecting the maximum inclined direction from eight neighbors. Then ridge lines are extracted by their steepest ascent lines on a surface.

The algorithm of the "steepest ascent method" is as follows:

Algorithm: *RidgeDetection*

Input *height* : a set of elevation values for each of *m* x *n* cells,
g_0 : threshold value
Output *color* : ridge detected map with grey denoted ridge cells
Initialization
Set *color* (*i*, *j*) := Green and *count* (*i*, *j*) := 0 **for all** *i* =1, ..., *m* and *j* =1, ..., *n*;
Evaluation
for all *i* =1, ..., *m* and *j* =1, ..., *n*
1: Evaluate *count* (*i*, *j*) by the followings
2: Select the cell (*k*, *l*) on the steepest ascent line from the cell (*i*, *j*),in the neighboring eight cells of cell (*i*, *j*).
3: **if** *height* (*k*, *l*) > *height* (*i*, *j*)
then *count* (*k*, *l*)++, replace (*i*, *j*) with (*k*, *l*) and **return to** line 2,
else quit.
Finalization
if *count* (*i*, *j*) > g_0 **then** *color* (*i*, *j*) := Grey **for all** *i* =1, ..., *m* and *j* =1, ..., *n*;

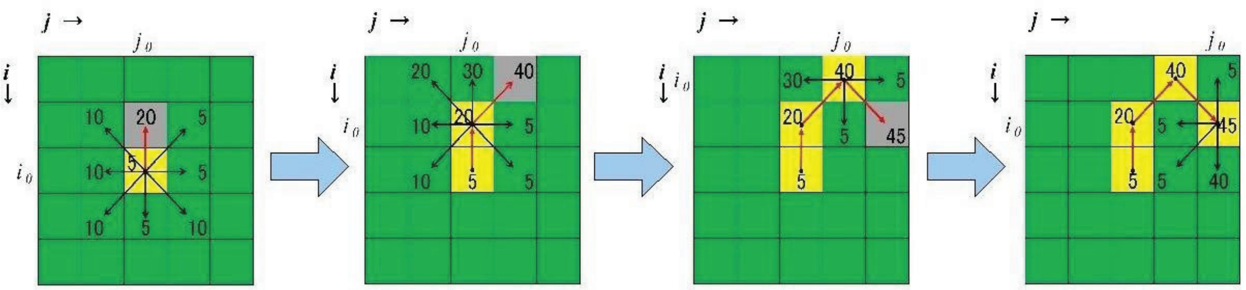

Figure 2. An example of replacements in the previous algorithm.

3.2. Comparison

Figure 3 (b) and (e) are ridge detected 3D terrain maps generated from the original map (a) around Mt. Tsukuba by applying our new method (g_0 = 5) and D.L.T. method with (2.1) (h_0 = -5), respectively. (e) indicates that ridges generated by D.L.T. method with (2.1) are too blurry to form ridge "lines". The similar incline also appears in other well-known methods to extract lines, edges and so force. On the other hand, we mention that ridge lines extracted by our method, (b), are sharper than ones in (e) by D.L.T. method with (2.1) and are recognized as clear lines.

Next, we consider maps for other threshold values. Figure 3 (c) and (d) is ones generated by our method with the threshold value g_0 = 30 and g_0 = 100, respectively. Amount of lines in the map (d) for g_0 = 100 too short to extract all ridge lines. However, the case of g_0 = 30, (c), is able to get adequate ridge lines and has few noises. This implies that the threshold value for (c) is optimal to extract ridge lines. In contrast, it is impossible to find the optimal threshold value by D.L.T. method with (2.1). Because (f) and (g) indicate that D.L.T. method with (2.1) does not only recognize small irregularities as ridges or extract few points but also both of h_0 = -20 and h_0 = -50 extract few points and breaks up ridge lines at steep slopes.

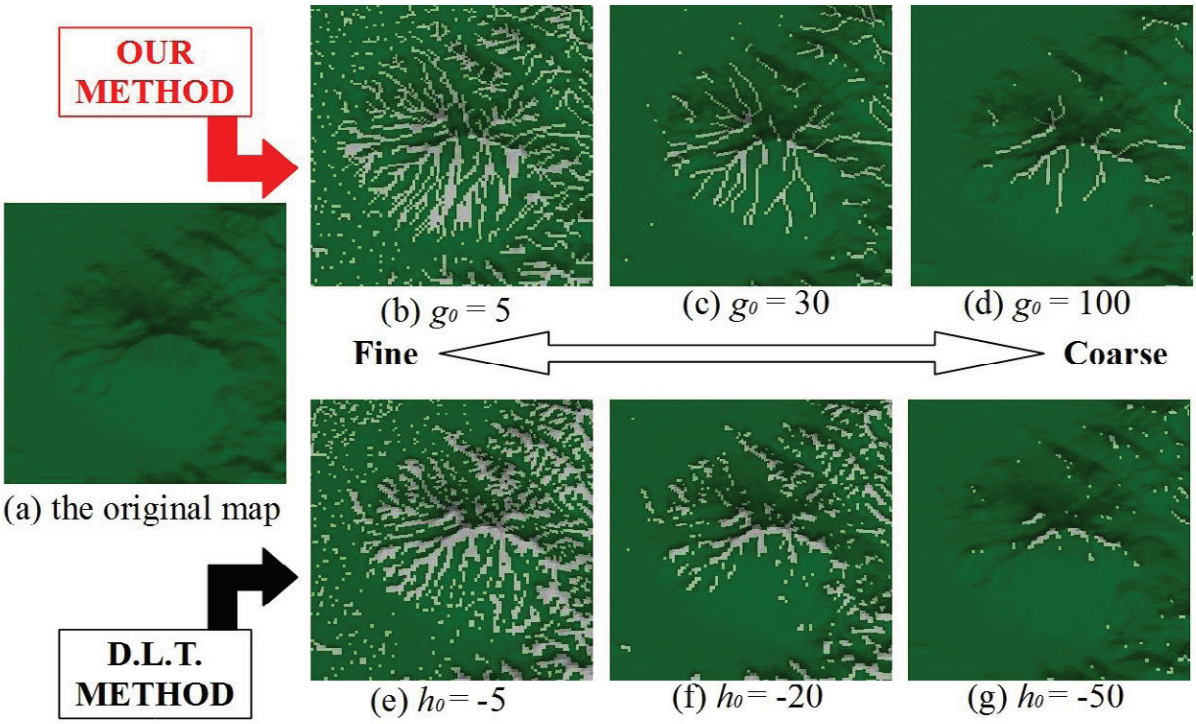

Figure 3. Ridge detected maps of Mt. Tsukuba. (All maps generated from NASA SRTM-3 DEM data.)

Moreover, we compare another area with the same threshold value. (h) and (i) in Figure 4 are ridge detected maps of Mt. Fuji. (h) generated by our method with g_0 = 30 also has clear ridge lines which are similar to owns of (c) in Figure 3. But (i) generated by D.L.T. method with h_0 = -20 also breaks up lines which are no longer ridge lines. This fact implies that our method makes it possible to detect ridge lines of various areas with the same threshold value and we can apply the simple ridge detection program with our algorithm for huge areas.

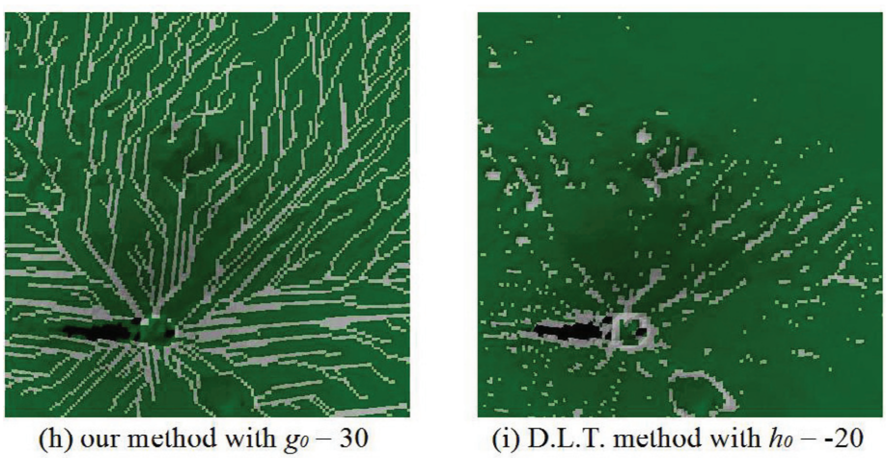

Figure 4. Ridge detected maps of Mt. Fuji. (All maps generated from NASA SRTM-3 DEM data.)

Therefore, “the steepest ascent method” is better for ridge detection than other well-known method such as D.L.T. method with (2.1) because of the following four claims.

Claim 1.
"The steepest ascent method" provides sharp and clear ridge lines, which are not blurry and have few noises even if threshold value is small. □

Claim 2.
"The steepest ascent method" does not break up lines and then provides continuous ridge lines. □

Claim 3.
"The steepest ascent method" is able to find the optimal threshold value to extract ridge lines. □

Claim 4.
"The steepest ascent method" provides ridge detected maps of the huge area with the optimal threshold value. □

Furthermore, Claim 1, 2, 3, and 4 indicate that the larger area map is can be generated by the simpler algorithm. In next section we will try to generate a huge map such as the entire area of Japan and Korea.

4. Ridge Detected Terrain Map Generation

4.1. Generation Process

Most of currently existing methods are applied to detect ridges for "local area" maps. On the other hand, the steepest ascent method is simple and suitable for global areas such as the entire area of Japan and Korea because we can apply our method to various areas with the same threshold value as mentioned in the previous section, Claim 4.

In this section, we apply our new method to 90m mesh NASA SRTM-3 DEM data (140 ZIP binary files in total) for the entire area of Japan and Korea.

Figure 5 is the generation process of "the steepest ascent method" in which 1, 2 and 3 are as follows.

1. We automatically convert each DEM data to internal list structure.
2. Next, we automatically convert each internal list structure to ridge detected VRML 3D terrain maps.
3. Finally, we manually assemble and convert ridge detected VRML 3D terrain maps to single ridge detected terrain map (JPEG) of entire area.

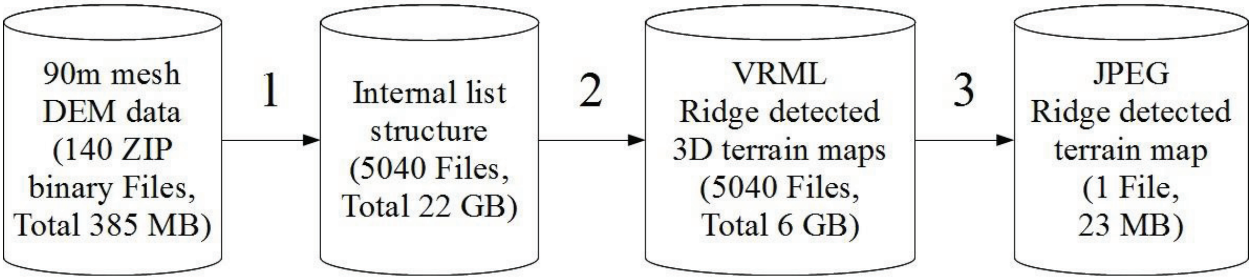

Figure 5. The diagram of the process to generate ridge detected terrain maps from DEM data.

4.2. Application

We generated the ridge detected entire Japan and Korea terrain map (j) in Figure 6 on Apple Mac Pro MB535B/A, 2x2.26GHz Quad-Core Intel Xeon with 16.0GB of 1066MHz DDR3 memory. The magnified map (k) is the entire area of Kanto region and the magnified map (l) is Mt. Tsukuba, with the ridge lines. (We can detect the ridges in (l) more clearly by changing the threshold values.)

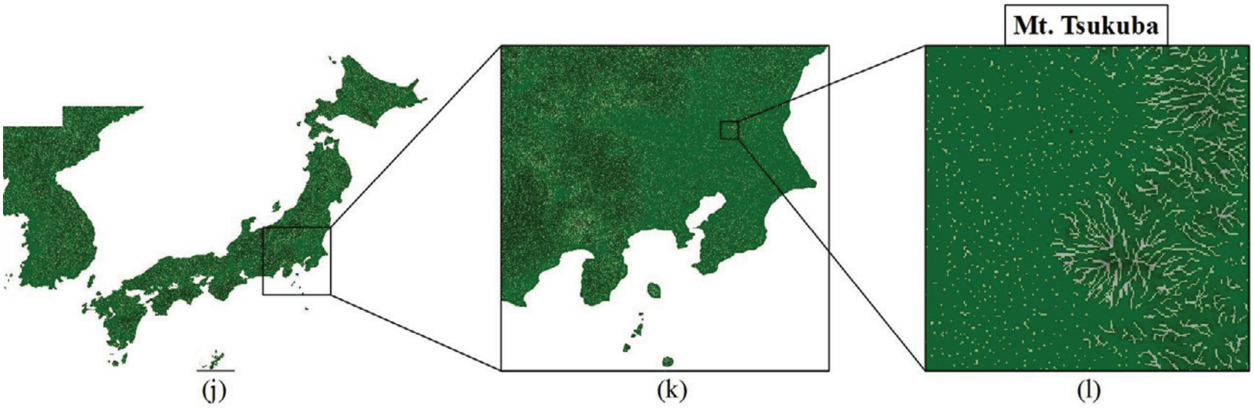

Figure 6. A ridge detected terrain map of the entire area of Japan and Korea. (All maps generated from NASA SRTM-3 DEM data.)

(j) is the outline map image of the entire Japan terrain map with about 4.5 x 10^7 cells in 3348 files (93 ZIP binary files) and Korea map with about 3.3 x 10^7 cells in 1692 files (47 ZIP binary files) showing ridge detected by the steepest ascent method. The execution time for the process to convert from DEM data of entire Japan and Korea region to VRML 3D terrain maps is 3569.3 seconds (38.4 seconds per map) and 1847.9 seconds (39.3 seconds per map), respectively. (k) is the map image of Kanto region including Mt. Tsukuba, showing the ridge lines (about 324km x 324km, about 7.2 x 10^6 cells). (l) is the map image of Mt. Tsukuba, showing the ridge lines (about 18km x 18km, about 4.0 x 10^4 cells).

5. Conclusion

We provide an algorithm for a ridge detection method called the steepest ascent method. Many previous studies are available to detect ridge lines for "local" areas but have some disadvantages for huge areas. Our method makes it possible to generate more effective displaying of ridge detected terrain maps for huge areas such as the entire area of Japan and Korea.

As future works, we consider ridge detections for digital elevation maps made from heterogeneous rectangles and extraction models for other geographic features (e.g., alluvial fans and craters).

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