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等高線地図から地形変化の解析

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古くから地理学的情報の多くは地図、特に等高線図として表現され、蓄積されているため、今後の地理学的情報処理においても、これらの等高線図として表現された情報の取り扱いが不可欠である。

著者らは前に、等高線型で表現されたモデルから格子点型のモデルへと変換する方法を開発し、報告した。等高線型のモデルとして与えられる情報は極めて多岐にわたり、これらのコンピューター処理に際しては、格子点型のモデルに変換して行う場合が多く、この方法は、例えば、地理学、リモートセンシング、縞画像解析等の分野において有効に利用できる。今回は、このデータ型変換システムをベースにして、等高線地図から地理学的な情報を抽出することを試みた。特に、地理学で重要である、断面形状の解析法、体積、表面積、重心等の立体的特性の計算法、傾斜の解析、異なった時期に得られた等高線地図間の差異の解析法などについて検討し、基本的な解析ソフトウェアの開発を試みた。

EXTRACTION OF GEOGRAPHICAL FEATURES FROM CONTOUR LINE MAPS

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Most of descriptive informations in geography is represented in the form of various kinds of maps and figures, among which, a contour line map is fundamentally important because many other figures can be derived from doing further works on the basis of a contour line map. However, a contour line map is not suitable for the automatic processing by a computer due to the irregular data structure. To solve the problem, a method to convert contour line surface model to mesh surface model was developed in the authors' earlier subject. The method is effective and applicable to some fields, such as geography, remote sensing, fringe pattern analyses and so forth.

Based on the developed method, a new system dealing with the extraction of geographical informations from contour line maps is proposed, which covers the processing of sectional shapes, the calculation of solid properties, the analyses of slopes and also the variation between several models obtained in different times. The methods and algorithms proposed here can undoubtedly be extended to the other fields where the contour-like data or mesh type data are used.

1. Introduction

Geography is the natural science that describes the surface of the earth and its associated physical, biological, economical and demographic characteristics. In geography, most of descriptive informations is represented in the form of various kinds of maps and figures, for instance, the contour line map, sectional shape, the figure of slope gradient, the figure of slope direction, the isogram, and even the three dimensional perspective. Among them, a contour line map is fundamentally important. In fact, many other figures can be derived from doing somewhat further works on the basis of a contour line map. An excellent geographier can use the contour line maps freely because some informations could be directly perceived through the senses. However, the direct interpretation of the patterns represented in contour lines is less promising for quantitative analysis due to the irregular data structure. To solve the problem, in the authors' earlier subject, we have developed an effective algorithm for complementing the data conversion from a contour line model to a mesh surface model, which is substantially useful for the automatic processing of geographic informations. The result suggests that we could set up a system that deals with the extraction of some important geographic features. For example, a subtraction of multi-term contour line models can show the changes in the area during the period, the statistical results of the surface area and solid volume are able to to afford the evidence and valuable reference data for the regional planning of land use and disaster harnessing. Moreover, a DTM (Digital Topography Model) system based on the mesh data in a specific region is helpful for the researches combined with the matched remote sensing data.

In this paper, the authors simply summarize the method of data form conversion from contour line surface model to mesh surface model which has been substantially improved in the latest programming and propose a new system that treats the extraction of geographic features on the basis of obtained mesh data. These features cover the the change of landscape, the quantitative values of solid volume and the surface area, sectional shapes, and slope features and the like. Figure 1 shows the configuration of our system which comprises two main stages. Detailed description of this system is available in the following chapters and other related references.

The authors believe that the application of the method is able to be extended to the other fields where contour-like data are used, such as in meteorology and in oceanic science and so on.

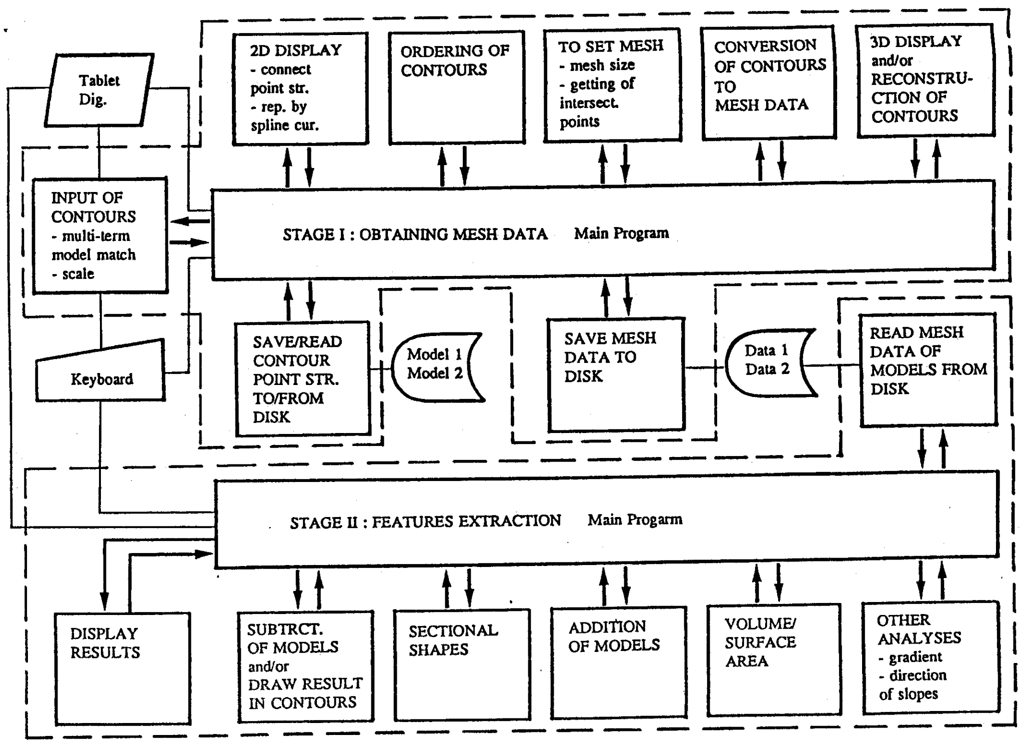
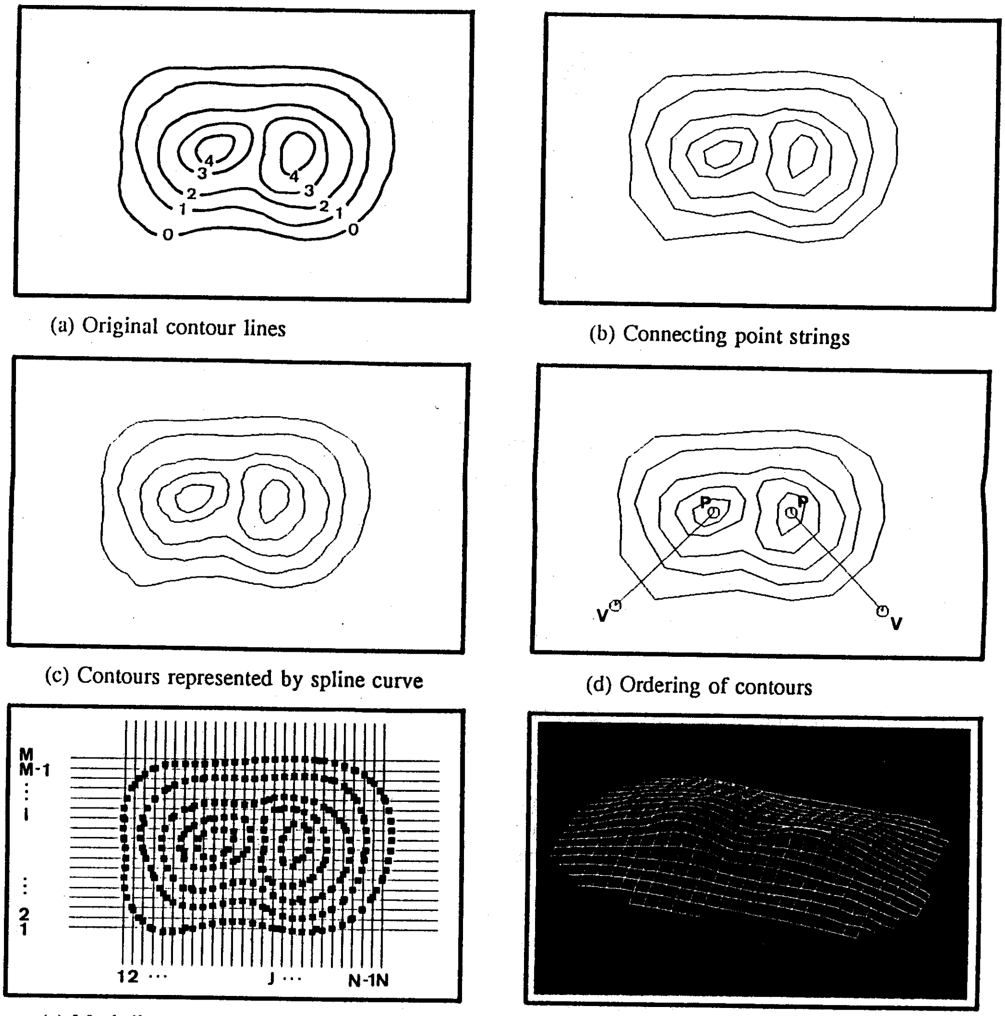


Figure 1. Configuration of the system dealing with data conversion and the extraction of geographic features

2. Inputing Contour Line Maps and the Data Form Conversion

Input Method of Contour Line Models

A contour line model in our experiment is basically input into the computer from a tablet digitizer by using the technique of RIFRAN II (M.Idesawa and T.Yatagai, 1982). The model input in the machine is represented by a group of point strings and is stored in the disk file so that it could be used in the further processing repeatedly. Furthermore, the model is able to be reconstructed by spline curves and to be ordered by finding out the interrelationships between contours, which are usually controlled by the peaks and valleies in the model (see Figure 2 (a) - (d)).



(a) Original contour lines

(b) Connecting point strings

(c) Contours represented by spline curve

(d) Ordering of contours

(e) Mesh lines and intersection points

(f) An example showing the application of obtained mesh data

Figure 2. A group of figures showing the method of complementing the data form conversion

In theory, a single model can be input from the tablet digitizer to the computer memory in any form for a good presentation, and particularly, for a good appearance on the screen of the graphic display terminal. However, for the dynamic analyses in a fixed area, more than two contour line models obtained in different time are involved. A good example is given by the research on the dynamic analysis of the formation and the deposition

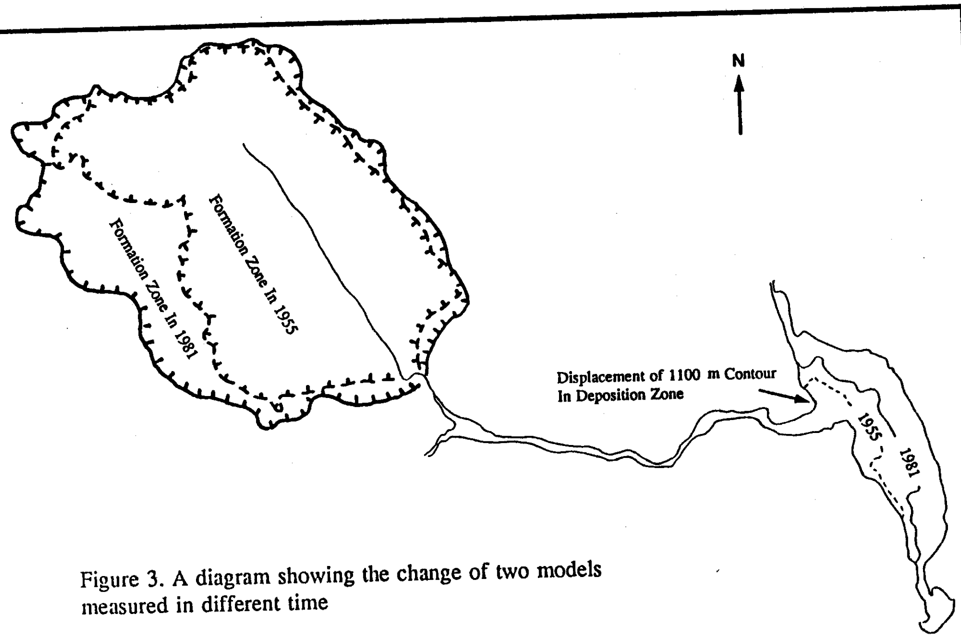


Figure 3. A diagram showing the change of two models measured in different time

zones of debris flows as shown in Figure 3 (J.Yuan and E.Sun, 1982). Therefore, the matching of multi-term contour line models has a considerable significance for the accurate calculation. Generally speaking, we need, at least, three points on each model to control the matching. However, it is usually not so easy to find out the corresponding points on different model. Fortunately, we can alternatively use the longitude and latitude of each contour line model to implement the matching of multi-models. In addition, the values of longitude and latitude of a model are also important for controlling the rotation and the translation of the model on the data level.

The scale factor is the other magnitude we should consider, for it controls the size and the scaling operation of the model. The scale of a model is obtained by inputing the value directly from the keyboard in our experiment.

The Data Form Conversion From Contour Line Surface Model to Mesh Surface Model

As the authors mentioned above, a contour line model is not suitable for the automatic processing by a computer. Hence, it is usually required to be converted into the other favorable data form such as mesh data. In the earlier research, the authors have already developed a method for complementing this conversion (K.Cheng and M.Idesawa, 1985,1986(a),1986(b)). The idea of the method is really simple and the results obtained show that the method is effective and is applicable to some fields. The main idea of the method is concluded as follows :

1) Firstly, the mesh grids constituted by the vertical and horizontal mesh lines are set up with a given size. Then the coordinates of each intersection points of these mesh lines with the contours are calculated automatically (see Figure 2 (e)).

2) Secondly, a most suitable mesh line which has maximum effective sampling points (intersection points) is chosen and a sectional shape corresponding to it is then decided by spline curves with parametric values on the basis of intersection points along the mesh line. Because the sectional shape is represented by spline curve, the coordinates of any point on it is easily decided, this is to say, the coordinates of each mesh point on this mesh line can be obtained in this manner.

3) Thirdly, the next mesh line will be chosen for further calculation. From the second mesh line, we use both intersection points on it and the mesh data on it (if any) which were obtained in the former processes to decide the sectional shape for the sampling points. By repeating the procedure, all mesh data can be decided eventually, even for the mesh points on those area where the contours are rare.

4) The most important algorithm in the procedure is how to find out the suitable mesh line to begin the

calculation. We give the details of the algorithm, in a FORTRAN-like form below :

```
C        SUBROUTINE SELINE : SELECT A SUITABLE
C      1 MESH LINE
         SUBROUTINE SELINE

           .
           .
           .

C        MESHX : NUMBER OF MESH LINES
C      1          IN X DIRECTION
C        MESHY : NUMBER OF MESH LINES
C      1          IN Y DIRECTION
C        ALL = MESHX + MESHY
C        IJUDGE(ALL) : USED TO JUDGE
C      1 WHETHER A LINE HAS BEEN CHOSEN.
C      2 IJUDGE(I) = 0, THE LINE HAS NOT
C      3 BEEN CHOSEN, ELSE, BEEN CHOSEN
C        NUMINT(ALL) : NUMBER OF INTERSECTION
C      1 POINS ALONG EACH MESH LINE
C        MANUM : MAXIMUM NUMBER OF NUMINT(ALL)
C        INUMB : VALUE FOR CONTROLLING
C      1          THE PROCEDURE

           .
           .
           .

C        CALCULATE THE DEVIATIONS OF EACH
C      1 MESH LINE ( THE NUMBER OF INTERSECTION
C      2 INTERSECTION POINTS ALONG IT SHOULD BE
C      3 LARGE THAN 3 ) AGAINST THE DISTANCE
C      4 BETWEEN EVERY TWO ADJACENT
C      5 INTERSECTION POINTS

         ILL = MESHX + MESHY

         DO 2999 I = 1,ILL
            DEVIAT(I) = 5000.0
 2999    CONTINUE

C        DEMIN : MINIMUM DEVIATION OF
C      1          MESH LINE WITH INUMB

         DO 3000 I = 1,ILL
            IF(NUMINT(I).LT.3) GO TO 3000

C           CALCULATE THE DEVIATION -- DEVIAT(I)
              .
              .
              .
 3000    CONTINUE

         INUMB = MANUM

 5050    IF(INUMB.LT.3) GO TO 3030
 2000    DO 2090 I = 1, ILL

            DEMIN = 5000.0
            IF(NUMINT(I).GT.INUMB) GO TO 2090
            IF(NUMINT(I).LT INUMB) GO TO 2090
            IF(IJUDGE(I).NE.0)     GO TO 2090
            IF(DEMIN.GT.DEVIAT(I)) GO TO 2080
            GO TO 2090
 2080       DEMIN = DEVIAT(I)
            IIN = I
 2090    CONTINUE

         IF(DEMIN.EQ.5000.0) GO TO 4000

         CALL MSHDTA(IIN)
         IJUDGE(IIN) = 100
         GO TO 2000

 3030    DO 3990 I = 1, IIL
            IF(NUMINT(I).GT.INUMB) GO TO 3990
            IF(NUMINT(I).LT.INUMB) GO TO 3990

            CALL MSHDTA(I)
            IJUDGE(I) = 100
 3990    CONTINUE

 4000    IF(INUMB.LE.2) GO TO 5000
         INUMB = INUMB - 1
         GO TO 5050
 5000    RETURN
         END

C        SUBROUTINE MSHDTA(II) : CALCULATE
C      1 THE MESH DATA ALONG II MESH LINE
         SUBROUTINE MSHDTA(II)

           .
           .
           .

         RETURN
         END
```

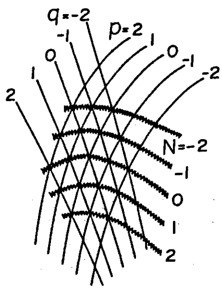
Figure 2(f) is an example showing the application of the obtained mesh data. This perspective figure is constructed by connecting the mesh points along vertical and horizontal mesh lines by spline curve with scaling and rotation. Its original contour line model is shown in Figure 2(a).

3. Extraction of Geographic Features

The obtained mesh data from contour line model is stored in the disk file for the further processes. From the point of view of geography, especially, of mountain disaster prevention, the study on the change and development tendency in a specific region is favorable. In fact, it is feasible to obtain these informations with the help of dynamic data. In a very special case, we are trying to use the mesh data obtained from contour line models in different time to extract some important solid features which are thought of as meaningful in the field of Geography.

Subtraction of Two solid models

Many methods can be used to complement the subtraction of solid models. Indicial equation method was used to represent the so-called secondary moire topography (H.Takahashi, 1970). Figure 4 shows the new moire pattern generated by overlapping two fine patterns and it can be analyzed by using the following indicial equations:



$$h_1 = p\Delta h = f_1(x, y)$$
$$h_2 = q\Delta h = f_2(x, y)$$
$$N = q - p = (h_2 - h_1)/\Delta h$$
$$or\ h_2 - h_1 = N\Delta h \qquad (1)$$

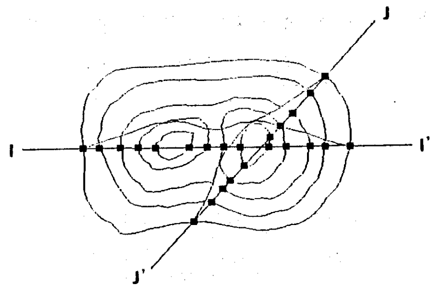


Figure 4. Conceptual diagram showing the secondary moire topography (H.Takahashi,1974)

Figure 5. Sectional shapes

Moire topography produced between two contour line systems shows up the contour line system of equal depth difference of the two surfaces. In theory, it can also be analyzed and represented by a computer if the original contour lines of each model are sufficiently dense and the difference between two models is relative large. However, it is very difficult to execute the analysis in such area where original contour lines are rare.

In our scheme, the mesh data obtained from two models are subtracted point by point. The subtraction of every two corresponding points in different model is stored in the other array. Like secondary moire pattern, the subtraction reflects the height difference between the two models. By using the algorithms to reconstruct contour lines, we can display this difference in a manner of the secondary contours that give one a direct impression on the change between two models.

Sectional Shape

Sectional shape is routinely used by a geographier for it reflects some section informations such as longitudinal slope, the cross section shape of gully bed and the like. The realization of drawing a sectional shape by a computer is really simple. An example of sectional shapes of our experimental model is shown in Figure 5.

Surface Area and Solid Volume

The volume, moments of inertia, and similar properties of solids are defined by three dimensional integrals over subsets of three- dimensional Euclidean space. The automatic computation of such integral properties for geometrically complex solids is important in CAD/CAM, robotics, and other fields (Y.T.Lee and A.G.Requicha, 1982). In the field of geography, the concept of the area of watershed is different from that of surface area and it is traditionally obtained with the help of a differential correcting method. However, the surface area of a watershed or a region is important for the harnessing of disasters or the planning of land use. In addition, the solid volume is usually required when one evaluates the change caused by landslides and mud flow. For instance, by calculating the volume of the subtraction of two models in a debris flow valley (measured in different times), we can know how much solid materials have been transported from the upper reach of the valley to the lower reach and how much solid materials have been silting on the deposition area in the lower reach, respectively, so that the evidence of the gravity caused from the disaster could be furnished to people to draw the attention to the problem.

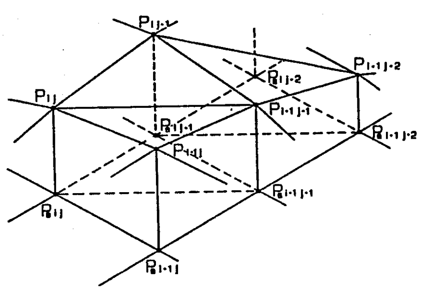
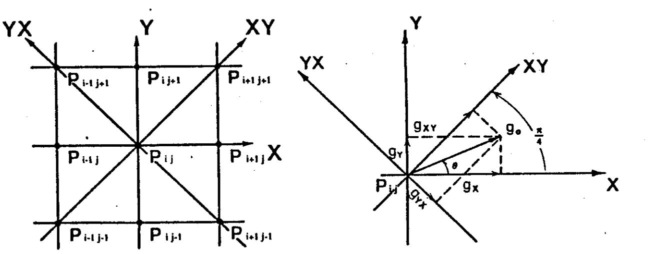


Figure 6. a figure showing a column at mesh point $\mathbf{P}_{B_{ij}}$



(a) Mesh points (b) Direction and gradient at point $\mathbf{P}_{ij}$

Figure 7. A figure showing the mesh points and the direction and gradient at point $\mathbf{P}_{ij}$

Many schemes of calculating the volumetric integrals have been summarized in Y.T.Lee and A.G.Requicha's article. However, the data form of mesh data is very similar to the spatial enumeration. Based on the obtained mesh data, we can easily set up an algorithm to complement the calculation of the surface area and solid volume.

Figure 6 shows a column $\mathbf{P}$ at mesh point $\mathbf{P}_{B_{ij}}$ constituted by a set of points

$$\mathbf{P} = \{\mathbf{P}_{B_{ij}}, \mathbf{P}_{B_{i+1j}}, \mathbf{P}_{B_{i+1j+1}}, \mathbf{P}_{B_{ij+1}}, \mathbf{P}_{ij}, \mathbf{P}_{i+1j}, \mathbf{P}_{i+1j+1}, \mathbf{P}_{ij+1}\} \tag{2}$$

where, $\mathbf{P}_{B_{ij}}, \mathbf{P}_{B_{i+1j}}, \mathbf{P}_{B_{i+1j+1}}, \mathbf{P}_{B_{ij+1}}$ are the mesh points, and $\mathbf{P}_{ij}, \mathbf{P}_{i+1j}, \mathbf{P}_{i+1j+1}, \mathbf{P}_{ij+1}$ are the points corresponding to the mesh points with height magnitude derived from the obtained mesh data. The model can be approximately represented by using such kind of column at different mesh point $\mathbf{P}_{B_{ij}}$. The summation of the area of each surface $\{\mathbf{P}_{ij}, \mathbf{P}_{i+1j}, \mathbf{P}_{i+1j+1}, \mathbf{P}_{ij+1}\}$ for all mesh points comprises approximately the surface area of the model, while the summation of the volume of each column $\mathbf{P}$ constitutes the total volume of the model. Below we discuss the fundamental calculations of both surface area and volume of the column $\mathbf{P}$ as shown in Figure 6.

The surface $\{\mathbf{P}_{ij}, \mathbf{P}_{i+1j}, \mathbf{P}_{i+1j+1}, \mathbf{P}_{ij+1}\}$ can be divided into two triangles, and the surface area can be given as a summation of the area of two triangles. Therefore, with the help of vector operations, some formulas are established below for the calculations of surface area of two triangles $\mathbf{T}_1 = \{\mathbf{P}_{ij}, \mathbf{P}_{i+1j}, \mathbf{P}_{i+1j+1}\}$,and $\mathbf{T}_2 = \{\mathbf{P}_{ij}, \mathbf{P}_{i+1j+1}, \mathbf{P}_{ij+1}\}$ and volume of the column $\mathbf{P}$, respectively.

1) The formula for calculating the surface area of $\{\mathbf{P}_{ij}, \mathbf{P}_{i+1j}, \mathbf{P}_{i+1j+1}, \mathbf{P}_{ij+1}\}$:

$$S_{ij} = \frac{|\,(\mathbf{P}_{i+1j} - \mathbf{P}_{ij}) \times (\mathbf{P}_{i+1j+1} - \mathbf{P}_{ij})\,|}{2} + \frac{|\,(\mathbf{P}_{i+1j+1} - \mathbf{P}_{ij}) \times (\mathbf{P}_{ij+1} - \mathbf{P}_{ij})\,|}{2} \tag{3}$$

where, S_{ij} represents the surface area of $\{\mathbf{P}_{ij}, \mathbf{P}_{i+1j}, \mathbf{P}_{i+1j+1}, \mathbf{P}_{ij+1}\}$.

2) The formula for calculating the volume of the column $\mathbf{P}$:

$$\begin{aligned} 6V_{ij} = {} & (\mathbf{P}_{ij} - \mathbf{P}_{B_{ij}}) \cdot \{ (\mathbf{P}_{i+1j} - \mathbf{P}_{ij}) \times (\mathbf{P}_{i+1j+1} - \mathbf{P}_{ij}) \} \\ & + (\mathbf{P}_{ij} - \mathbf{P}_{B_{ij}}) \cdot \{ (\mathbf{P}_{i+1j+1} - \mathbf{P}_{ij}) \times (\mathbf{P}_{ij+1} - \mathbf{P}_{ij}) \} \\ & + (\mathbf{P}_{B_{i+1j}} - \mathbf{P}_{B_{ij}}) \cdot \{ (\mathbf{P}_{B_{i+1j+1}} - \mathbf{P}_{B_{i+1j}}) \times (\mathbf{P}_{i+1j+1} - \mathbf{P}_{B_{i+1j}}) \\ & \qquad + (\mathbf{P}_{i+1j+1} - \mathbf{P}_{B_{i+1j}}) \times (\mathbf{P}_{i+1j} - \mathbf{P}_{B_{i+1j}}) \} \\ & + (\mathbf{P}_{B_{ij+1}} - \mathbf{P}_{B_{ij}}) \cdot \{ (\mathbf{P}_{ij+1} - \mathbf{P}_{B_{ij+1}}) \times (\mathbf{P}_{i+1j+1} - \mathbf{P}_{B_{ij+1}}) \\ & \qquad + (\mathbf{P}_{i+1j+1} - \mathbf{P}_{B_{ij+1}}) \times (\mathbf{P}_{B_{i+1j+1}} - \mathbf{P}_{B_{ij+1}}) \} \end{aligned} \tag{4}$$

where, V_{ij} represents the volume of the column $\mathbf{P}$.

Other Analyses

Finally, the application of the obtained mesh data is expected to be extended to the analyses of slope characteristics such as the gradient of the slope and the direction of slope. As we know, both the gradient and direction of the slope can be decided by analyzing the relationships between a point (in three dimension) and the points close to it. On the mesh data level, the analyses are easy to be realized on the basis of vector operations.

As shown in Figure 7(a), $\mathbf{P}_{ij}$ is a point with three dimensions on the mesh surface. g_0 expresses the magnitude of slope gradient at the point $\mathbf{P}_{ij}$ (always positive) and θ represents the direction of the slope at the point $\mathbf{P}_{ij}$ (see Figure 7(b)). In terms of Figure 7(b), a group of formulas are easily obtained :

$$\begin{aligned} & g_x = g_0 \, cos theta, \quad g_y = g_0 \sin\theta \\ & g_{xy} = g_0 \cos(\frac{\pi}{4} - \theta), \quad g_{yx} = g_0 \sin(\frac{3\pi}{4} - \theta) \end{aligned} \tag{5}$$

where, g_x, g_y, g_{xy}, and g_{yx} are the magnitudes of gradient for X , Y , XY and YX direction, respectively.

If the surface is represented by height Function H, g_x, g_y, g_{xy}, and g_{yx} can be obtained by using the following formulas theoretically :

$$g_x = \frac{\partial H}{\partial x}, \quad g_y = \frac{\partial H}{\partial y}, \quad g_{xy} = \frac{\partial H}{\partial xy}, \quad g_{yx} = \frac{\partial H}{\partial yx} \tag{6}$$

where, $\frac{\partial}{\partial x}$, $\frac{\partial}{\partial y}$, $\frac{\partial}{\partial xy}$, and $\frac{\partial}{\partial yx}$ represent differentiation for the direction X, Y, XY, and YX, respectively. Generally speaking, it is very difficult to establish such a kind of perfect height function from mesh data. However, they can be easily decided by using the parameters of spline curves representing the sectional shapes for each direction at the point. The parameters can be determined by points surrounding the point $\mathbf{P}_{ij}$. Theoretically, the results of g_x, g_y, g_{xy}, and g_{yx} derived from spline curve parameters should be equal to that from (6). In addition, if the mesh points that comprise the model are close enough, (6) can be approximately expressed as :

$$g_x = \frac{h_{i+1j} - h_{i-1j}}{2}, \quad g_y = \frac{h_{ij+1} - h_{ij-1}}{2}$$

$$g_{xy} = \frac{\sqrt{2}\,(h_{i+1j+1} - h_{i-1j-1})}{4}, \quad g_{yx} = \frac{\sqrt{2}\,(h_{i-1j+1} - h_{i+1j-1})}{4} \tag{7}$$

where, h_{i+1j}, $\cdots$, h_{i-1j+1} and h_{i+1j-1} mean the height magnitude of the points surrounding the point $\mathbf{P}_{ij}$. Now that we can obtain the values of g_x, g_y, g_{xy}, and g_{yx}, we can then decide g_0 and θ easily in terms of (5), that is,

$$g_0 = \sqrt{g_x^2 + g_y^2}, \quad \tan\theta = \frac{g_x}{g_y} \tag{8}$$

and

$$g_0 = \sqrt{g_{xy}^2 + g_{yx}^2}, \quad \tan\theta = \frac{g_{xy} - g_{yx}}{g_{xy} + g_{yx}} \tag{9}$$

In theory, results from (8) and (9) should be the same, or there is no big difference from each other. In general, we calculate g_0 and θ according to both (8) and (9) and make a comparison between the results derived from each one. Thus, the results will be more believable, especially, for instance, at the saddle-like points.

4. Conclusion

We have described a method to complement the conversion from contour line surface model to mesh surface model. The result obtained from the conversion shows this method is effective and applicable and it also introduces the potential extension of the application to some fields, especially the field of geography. Using the mesh data, some important geographic features can be extracted. These features cover a wide spectrum, such as the sectional shape, the surface area, the solid volume and slope characteristics and so on. Moreover, by analyzing two models measured in different time in the same place, some dynamic informations showing the change during the period can be furnished. At current stage, the programming of these application algorithms are substantially under way.

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