A Simplified Data Form Conversion Method From Contour Line Surface Model to Mesh Surface Model

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One of the main problem in the data conversion processing from contour line type model to mesh type surface model is how to determine the mesh point values with minimum error at the mesh points in the areas where there are only a few contour lines. A simplified conversion method is proposed in this article. Mesh lines are superimposed onto the contour lines and each intersection of mesh lines with contour lines is calculated and used as a sampling point. A sectional shape along the mesh line having the most effective sampling point is chosen first, and mesh point values along the mesh line are decided. These mesh point may be used as the sampling points in the following processing. The above processing is repeated until all required mesh point values are decided. The idea of the method is simple enough, however, it is possible to determine the mesh point values quite precisely even in the areas where there are fewer contour lines.

1. Introduction

Contour line surface model is widely used to represent the 3-D surface and is very useful for understanding the surface structure of an object to human observers. It will continue to be an important and popular method for human observers because some informations could be directly perceived through the scenes. The applications of contour line surface model can easily be extended to many fields, such as the topographic map in geosciences and the atmospheric pressure isogram in meteorology and the like. With the help of interferometric technique such as the moire topography technique [1, 2] and so forth, we can acquire some fine fringe patterns which correspond to the contour lines showing the 3-D structure of an object. However, the results and discussions in the latest research suggest that the direct interpretation of these patterns, for instance, moire pattern, is less promising for quantiative analyses [3]. The problem refers to many factors, one of which is that the data form of the contour lines (countour-like patterns, etc.) is not suitable for automatic processing by computers. The contour line model, therefore, is usually required to be converted into an appropriate form by using some interpolation methods. For example, a mesh surface model consisting of a set of mesh grids whose vertices are lying on the surface is commonly used as a substitution. Many strategies are proposed to estimate the values at these mesh points as reviewed in [3]. However, a fast and simple method with high precision to implement the conversion from contour line surface model to mesh surface model is required. It may be an interesting subject to decide the mesh values in the area of the surface where the distribution of the contour lines are rare.

In this article, the authors describe a simplified conversion method of the data from contour line surface model to mesh surface model (Fig. 1). One of the focus point in the present method is how to determine the mesh data with minimum error on the mesh line on which there are only a few intersection points with contour lines.

2. Method of Data Form Conversion from Contour Line Surface Model to Mesh Surface Model

2.1 Contour Line Type Representation Method

Fringe patterns such as interferometric fringe pattern and moire fringe pattern have been widely used for noncontact measurement of the surface shape, the deformation, the displacement and the like of an object in various fields. These fringe patterns are very useful for extracting qualitative information, but are often ex-

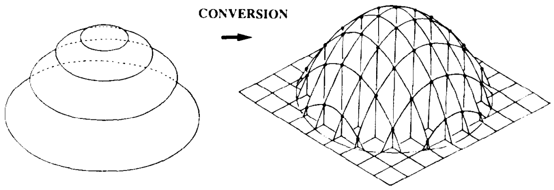

Fig. 1 A conceptual figure showing the data form conversion from contour line surface model to mesh surface model.

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tremely tedious and time-consuming for evaluating quantitative data. To solve this problem, two kinds of interactive fringe pattern analysis systems by the names of RIFRAN I and RIFRAN II [4] were developed in one of the author's earlier work. RIFRAN I builds a sectional shape type model from the fringe pattern acquired by TV camera semi-automatically by applying image processing techniques. RIFRAN II is mainly used for the interactive input and construction of the contour line type model. Moreover, some semi-automatic man-machine interactive and even full automatic methods of contour line input from contour line map or fringe patterns are also available. In the case of RIFRAN II, the initial data of contour lines obtained in the computer are a set of coordinate data of the contour without ordering (i.e. without height information). The model is constructed by smoothing these data by the spline curve fitting and classifying the contour by the order using correspondence functions. The quality of contours represented by the spline curve in a computer is substantially dependent upon the distance of adjacent digitized points on a contour line. The shorter the distance is, the better the contour line model obtained will be. However, the problem refers to the amount of data and the digitizing-time required which have to be also considered. In general, it is efficient to digitize more points on the segment where the curvature is larger, and relatively fewer on the segment where the curvature is smaller.

2.2 The Principal Idea of the Conversion Method [5, 6]

Depending upon the accuracy needed to obtain, a different sized equidistant orthogonal grid of lines along X, Y coordinates is superimposed onto the contour lines. In a three dimensional space, each of these lines (hereafter referred to as mesh line) corresponds to a plane which is perpendicular to the X, Y-plane and ordered contour lines would be regarded as the intersecting lines of an object cut by a set of planes which are parallel to the X, Y-plane at different heights. Therefore, one can think that the plane corresponding to each mesh line intersects with contour lines. The height value at grids comprised by these orthogonal lines should be determined.

As illustrated in Fig. 2, there are several intersections of mesh lines with contours. The number and the distribution of these intersection points on the mesh line are different from each other. The X, Y coordinates of all these intersection points should be calculated while their Z coordinates can easily be obtained from the order of the contour lines on which the intersections are lying. These intersection points are treated as the sampling points used for the determination of the sectional shape. The sectional shape corresponding to the mesh line which has the most effective sampling points would be obtained first. The sectional shape, in our experiment, is expressed by the third order spline curve with parameters. That is to say, we could determine any mesh values on the same sectional shape by a proper interpolation method if we know the position of the mesh point along the mesh line. Taking the other mesh lines in succession, the corresponding sectional shapes can be decided. Generally speaking, the mesh line with more effective sampling points would be selected earlier in the processing. The number of the effective sampling points on the mesh line play a very important role as we have described briefly. For those mesh lines that have fewer intersection points, we can use both the intersection points and the newly determined mesh values derived from the former processing. Thus, the difficulty to get accurate mesh data in such an area where the contours are rare would be solved in this method. In the remainder of this article, we will describe the method in detail with some concrete examples.

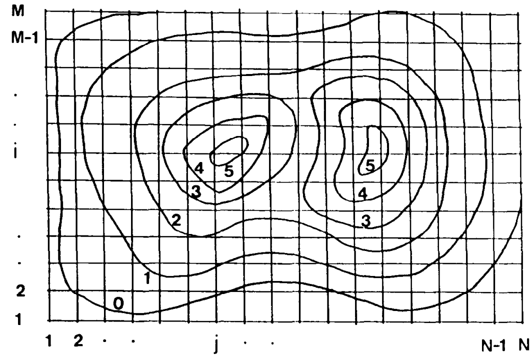

Fig. 2 A contour lines surface and mesh grid system. Numbers attached to the contour lines represent the order levels of contour lines. $(1, \cdots, j, \cdots, N)$: vertical mesh lines; $(1, \cdots, i, \cdots, M)$: horizontal mesh lines.

Figure 2 shows the superimposing of orthogonal mesh lines onto contour lines, from which it is easy to understand the importance of the number of the intersection points (the effective sampling points) in determinating the mesh values. For example, there are only two intersection points on the second mesh line in the vertical direction. In fact, it is impossible to decide the corresponding sectional shape by using only two points because the minimum number of sampling points necessary for the third order spline curve is four. On the other hand, there are more effective sampling points on the mesh line i in X direction and j in Y direction, respectively, by which the sectional shapes corresponding to them can be described very precisely. As a result, we can accordingly derive the accurate mesh values from the interpolation calculation for these sectional shapes. Now consider the mesh line i. When we select this mesh line, a set of mesh values can be obtained, including the one which (with calculated height) is just lying on the second mesh line in the direction perpendicular to mesh line i. Furthermore, after calculating more mesh values on the mesh lines that are parallel to the mesh line i, more mesh values are also determined on the second

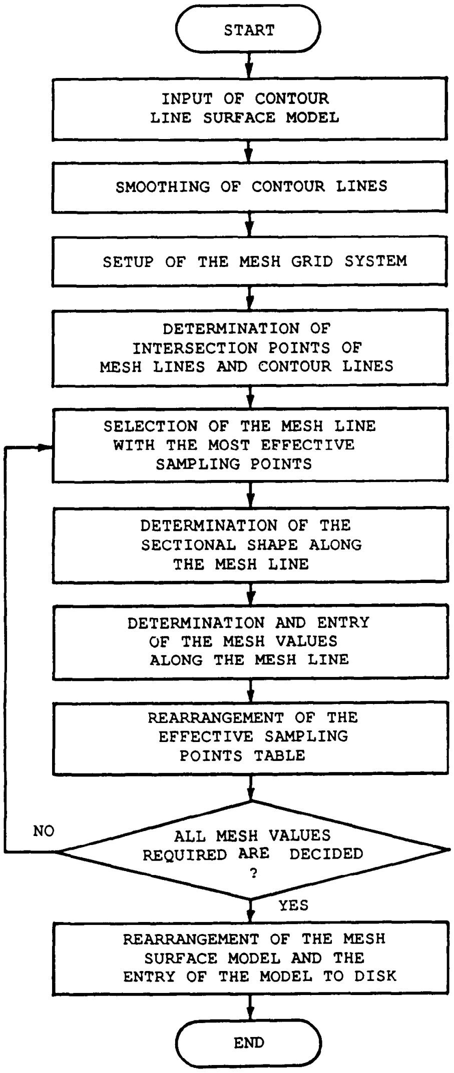

Fig. 3 A general flow diagram of the data form conversion procedure from contour line surface model to mesh surface model.

mesh line in Y direction. We could, of course, not be assured that every mesh value could be determined in this manner. However, in the subsequent processing, we can use both the two intersection points and the mesh values derived from the calculations on other mesh lines, although these two kinds of points are of different importance. It is the mesh values on the mesh line like this which is distributed in the area where the contour lines are rare. In programming, we just select a mesh line on the basis of the number of the sampling points on each mesh line, from the largest to the smallest, taking into account another considerations which will be treated later, until all mesh values required in the model are determined.

2.3 The Realization of the Data Form Conversion

The data form conversion method mentioned above has been substantially realized in programming and some satisfactory results have been achieved. Fig. 3 is a general flow diagram showing the procedure of the data form conversion from contour line surface model to mesh surface model. The original contour line model is input into the computer by using a tablet digitizer and the distance between adjacent points is controlled manually. The input model is stored as a file and it can be used at any time when any further processing is required. The model expressed as a string of point data is smoothed by spline curve and is ordered by pointing manually the peaks and valleys in the model. Of course, it is also possible to feed contour line models built by other methods and be accumulated in a file. In the next step, a set of mesh lines are superimposed onto the contour line model with the desired size of the grid and the intersection points of these mesh lines with contour lines are calculated. Figure 4 shows the data structure related to the data form conversion procedure, among which PX, PY are used to register the Y, Z coordinates for vertical direction and X, Z coordinates for horizontal direction, respectively, while their corresponding X and Y coordinates can easily be determined due to the fixed grid size. Then, we reach the main part of the procedure, that is to select the most suitable mesh line and to calculate the corresponding sectional shape so that we can determine the mesh values on the sectional shape (Z coordinate of the mesh grid). We begin this part with a mesh line which has the most effective sampling points. And we must also consider problem of the order of selection of the mesh line taking into account the priority which will be treated in great detail below. Therefore, there is some space left in Fig. 4 for registering the number of the sampling points (intersection points) along each mesh line and the number of determined mesh values along the mesh line at current stage. The table will be rearranged once after the processing for a selected mesh line. Thus, the procedure will repeat selecting the mesh line and other processings accordingly until all mesh values required in the model have been determined. Lastly, with some rearrangements, the model expressed in mesh values is stored as a file for further processing. The configuration of the system dealing with the data form conversion from contour line surface model to mesh surface model is shown in Fig. 5.

Figure 6 is a contour line model showing the human breast, the original patterns of which is derived from the moire topography picture that is used in medical field for the analysis of a human body. The sectional shapes are obtained in a function separate from the data form conversion procedure. Note that the extension of the sectional shape **BB**′ is obviously limited in the lower part. The problem can be solved in our two-direction interpolation method mentioned above. Fig. 7 shows the mesh grid system placed onto the contour line

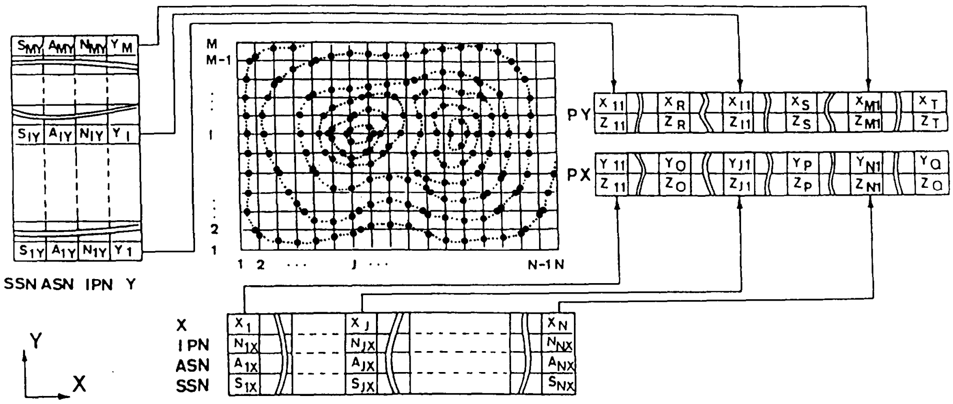

Fig. 4 An example of the data structure related to the procedure in which the mesh line is selected only on the basis of the number of sampling points. M and N are the numbers of mesh lines along Y, X directions respectively; PX = Y, Z coordinates of the intersection points along a selected mesh line in Y direction (X value is given automatically); PY means that in X direction. IPN = number of intersection points on a mesh line with contour lines; ASN = number of determined mesh points on the mesh lines; and SSN = IPN + ASN.

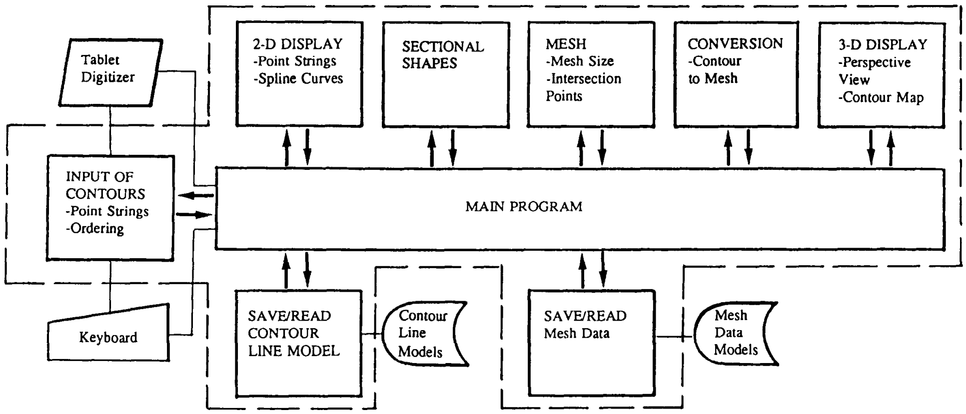

Fig. 5 Configuration of the system dealing with the data form conversion.

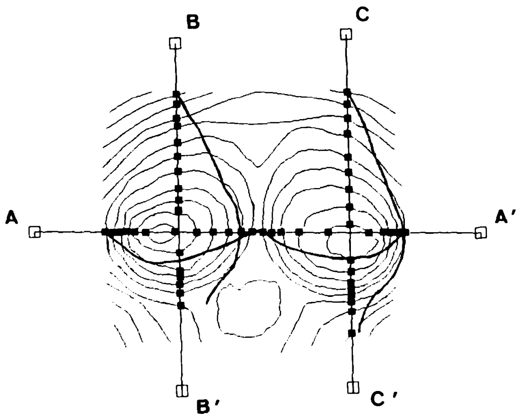

Fig. 6 A contour line model showing the human breast, which is input, ordered and stored in the computer interactively. The sectional shapes are obtained in a function separately from the data form conversion. Note that the extension of the sectional shape BB′ is obviously limited in the lower part.

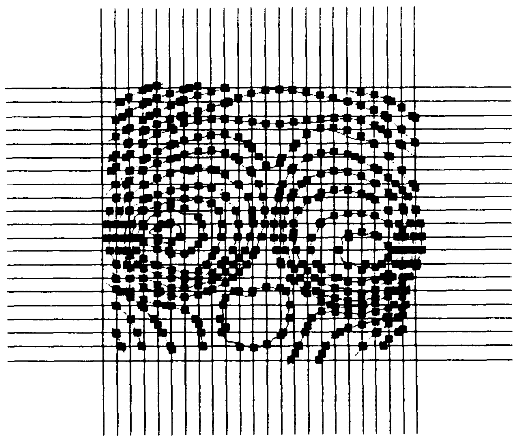

Fig. 7 An example of mesh grid system placed onto contour lines model and the automatic determination of intersection points of mesh lines with contour lines.

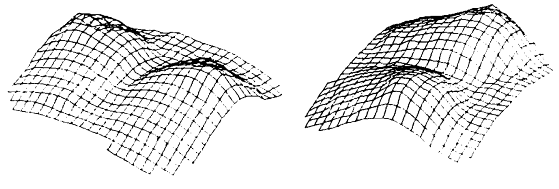

Fig. 8 Examples showing the 3-D perspective figures on the basis of the obtained mesh data in different observation views, the original contour lines model of which is shown in Fig. 6.

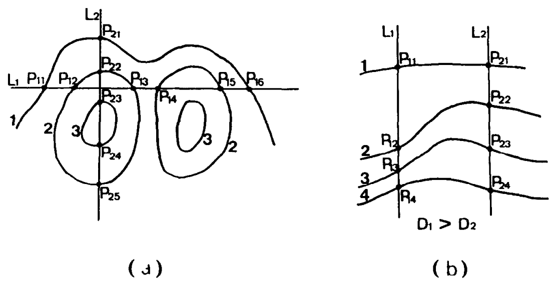

Fig. 9 Considerations on the priorities for the selection of mesh lines with the same number of effective sampling points.

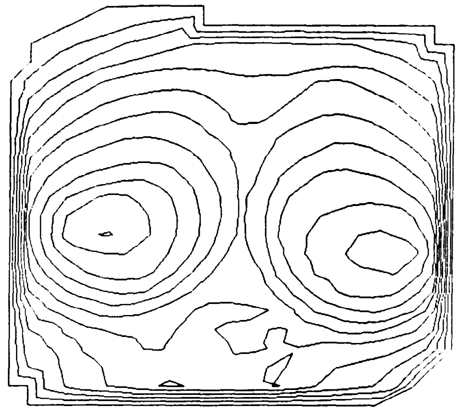

Fig. 10 An example of contour line map obtained from the mesh data which are converted from an original contour lines model.

model and the automatically determined intersection points of mesh lines with contour lines. Some 3-D perspective figures in different observation view drawn on the basis of the obtained mesh data are shown in Fig. 8. The original contour line model is shown in Fig. 6.

2.4 Considerations on the Order of Selection of Mesh Lines

As we mentioned above, we consider the problem of the selection of the mesh line to calculate the mesh values. It is important to select the most effective mesh line at each stage. Since the effective sampling points implies the effectiveness of the sampling points on the mesh line in determining the sectional shape when they are used, we can judge the effectiveness of a mesh line just on the basis of the number of effective sampling points on it. For a contour line model with a square or a square-like shape, in which the lengths of the mesh line are equal, this scheme is acceptable, but for this with rectangle shape, we may have to select the mesh line in terms of the number of sampling points in a unit length. However, there are some aspect that we have to consider. For example, which mesh line should be selected first if these are more than one mesh line with the same number of sampling points. We merge the cases into the problems of priority. A mesh line with the highest priority means that it will be selected first.

As shown in Fig. 9(a), the first case is that there are more than two continuous intersection points with the same order on the mesh line L_1. It is very difficult to use this kind of intersection points to decide the sectional shape because we can not judge the situation of concave and convex in the region. The fact can be explained mathematically. Supposing that the height of the mesh line on which the continuous intersection points with the same order are lying is h_0, the height difference between the two adjacent contours is Δh, then the height of mesh value between the two intersection points with the same order h would be:

$$h_0 - \Delta h < h < h_0 + \Delta h$$

the uncertainty for h is $2\,\Delta h$, while the uncertainty for the mesh value between the intersection points on the mesh line like L_2 is only Δh. Therefore, the lower priority should be given to the mesh line L_1.

Figure 9(b) gives another case that indicates some lines on which there are the same number of intersection points. On L_1 the distance between P_{11} and P_{12} is much larger than the distance between P_{12} and P_{13} and that between P_{13} and P_{14}, but we cannot find so large differences between every two adjacent points on L_2. We can describe this difference by calculating the deviations against the substance between every two adjacent points on L_1 and L_2, respectively. In the case of Fig. 9(b), the deviation D_1 of L_1 is larger than D_2 of L_2. The line with smaller deviation against sub-distance between every two adjacent intersection points on it has a higher priority. The reason for our doing this is from the mathematical background below. Supposing that W_m is the mean width (distance) between every two adjacent intersection points on a mesh line, σ_s is the standard deviation of the distances against the mean width and α is a parameter, then we think the description of a sectional shape would not be so good if the distance W of the adjacent intersection points we used is too large. That is, the intersection point would be excluded if

$$W > W_m + \alpha\sigma_s$$

Generally speaking, it is possible to determine the sectional shape more precisely for the mesh line which is crossing almost perpendicular to the contour lines than

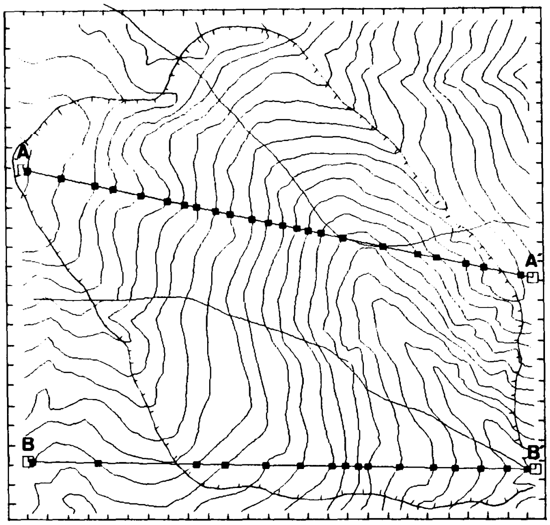

Fig. 11 A computer-represented contour map which contains a debris flow basin. Scale on the frame corresponds to the mesh size.

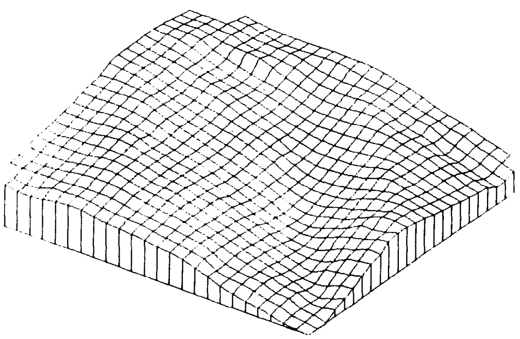

Fig. 12 An example of the perspective view displayed from the mesh surface model which is converted from contour line surface model shown in Fig. 11.

that for the mesh lines which are crossing far from the right angle. This property may also be effective for determining the priorities for the mesh line selection.

In our procedure, we have considered all these two kinds of priorities in evaluating the effectiveness of sampling points with some directly perceived methods.

2.5 Reconstruction of the Contour Lines on the Basis of Obtained Mesh Data

Figure 10 shows an example of the result of the inverse processing for the data obtained from the conversion method described in the above sections, which is constructed on the basis of the obtained mesh data from the original contour lines. The program used here for plotting contour lines was originally developed by E. Munro [7]. It may be a problem how to judge the precision of the data form conversion method quantitatively. However, this inverse processing gives us a direct impression of the effect of the conversion method. Of course, generating true contour lines requires more information than finding a group of planar points [8]. The procedure used here for the construction of contour lines is obviously not so suitable. For instance, sometimes we expect the appearance of some unlooped contour lines, but the result shown here has only looped contour lines. Except for the boundary area the result, we think, is quite satisfactory and the conversion method is then proved to be effective.

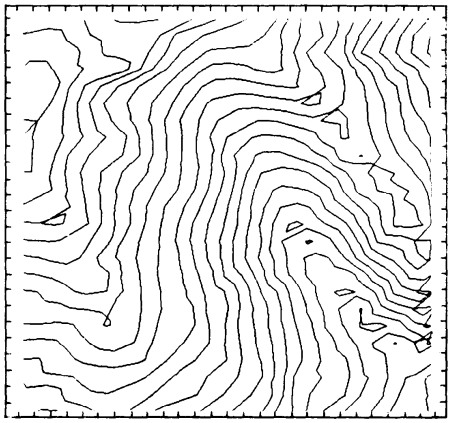

Fig. 13 An example of the contour map obtained from converted mesh surface model by the inverse conversion.

2.6 Experimental Results

The conversion method described in this article has been implemented in our system. Figure 11 is a computer-represented contour line map which contains a debris flow basin in a mountain area. The sectional shapes corresponding to lines **AA'** and **BB'** indicate the complicated topography in the area. After the conversion of this model to mesh data by using the conversion method described above, an example of the perspective view of the basin from the mesh surface model is shown in Fig. 12. And Fig. 13 shows the contour line map obtained from converted mesh surface model by the inverse conversion. In comparison with the original computer-represented contour line map, we can feel the effectiveness of our conversion method. In some area, such as in the lower-right corner, the reconstruction of contour lines seems not so satisfactory. The problem may be rising from two reasons. One of them is from the incompleteness of the contour producing program itself because we have to consider many factors for obtaining the very accurate contours, the other one might be from the size of the mesh grid. If we make the size of the mesh grid much smaller, the result may be greatly improved.

3. Conclusion

A simplified data form conversion from contour line surface model to mesh surface model is described. A set of lines which comprise the mesh grids are superimposed onto the contour line model and the intersection points of the lines with contour lines, which are treated as sampling points in determining sectional shape, are calculated automatically. A mesh line which has the most effective sampling points is selected and the sectional shape corresponding to it is determined. By using interpolation technique, we can determine the mesh values on the sectional shape and these mesh values are used as the sampling points together with the original one in the following processing. For the mesh line having the same number of effective sampling points, the priority of the selection is introduced taking into account the effectiveness of each sampling point. The above processing is repeated until all mesh values required are determined. An inverse processing for producing contours on the basis of the obtained mesh data is introduced to check the effectiveness of the conversion method. The result of experimental data shows that the data form conversion method described in the article is effective and satisfactory. This conversion method can be extended to many fields where contour-like data are used.

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References

1. Ota, Y., Arai, H. and Tokumasu S., et al. An Automated Finite Polygon Division method for 3-D Object, *IEEE Computer Graphics and Applications* (April 1985), 61.
2. Takasaki, H. Moire Topography, *Applied Optics*, **9**, 6 (June 1970) 1467–1472.
3. Hierholzer, E. et al. Computerized Data Acquision and Evaluation of Moire topograms and Rasterstereographs, *Moire Fringe Topography and Spinal Deformity*, Gustav Fisher Verlag (1983) 233-240.
4. Idesawa, M., Yatagai, T. and Soma T. RIFRAN: Interactive Fringe Pattern Analysis and Processing System, Proceedings of the first IEEE Computer Society International Symposium on Medical Imaging and Image Interpretation, Berlin, F. R. Germany (October 1982) 554–559.
5. Cheng, K. and Idesawa, M. A Simplified Interpolation and Conversion Method of Contour Surface Model to Mesh Surface Model, *Journal of Robotic Systems*, **3**, 3, 237–247, John Wiley & Sons, Inc., New York (1986).
6. Cheng, K. and Idesawa, M. A Simplified Method of Data Form Conversion From Contour Line Surface Model to Mesh Surface Model, *Proceedings of the Eighth International Conference on Pattern Recognition*, 582–585, Paris, France, 1986 (by IEEE Publ. Inc.).
7. Munro, E. A Set of Computer Program for Calculating the Properties of Electron Lenses, Department of Engineering, University of Cambridge, CUED/B-Elect TR45 (1975).
8. Satterfield, S. and Rogers, F. A Procedure for Generating Contour Lines From a B-Spline Surface, *IEEE Computer Graphics and Applications* (April 1985) 71–75.

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