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Third Turkish-German Joint Geodetic Days
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AN APPROACH FOR DETERMINATION OF CHARACTERISTIC POINTS OF CONTOURS

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Skeleton lines (i.e. ridge and drainage lines) may be supposed to be the signs of characteristic points of contours and used as tools in determination of characteristic points of contours. If a contour point is a point of a skeleton line or the nearer end point of a contour segment crossed by a skeleton line segment then it may be assumed as the characteristic point of the contour. Characteristic points are automatically determined during the process of derivation of skeleton lines from contours in accordance with the method developed by Aumann et al. [1991].

1. INTRODUCTION

Contours are the most important tools for geometric representation of relief, in other words, for representation of relief with its position and height. In this context, contours are used in several computations related to relief (e.g. slope computations, intervisibility analysis, etc.). Moreover, a new representation of a relief at smaller scale is obtained by means of generalization of contours. So, characteristic parts of contours should be taken into consideration in such computations or processes.

Since the skeleton lines are the lines drawn for emphasizing the characteristic parts of relief, the parts of contours where the skeleton lines exist may be assumed as the characteristic parts of contours.

Skeleton lines are the ridge and the drainage lines and may be considered as the bridges between contours, in other words, skeleton lines are the cartographic signs of geomorphological relationship between contours.

Aumann [1991] describes the skeleton lines in accordance with the steepest slope lines as "Among the steepest slope lines, the skeleton line is the one with minimum slope." Steepest slope lines are the paths traced through the direction or the directions of the steepest slope (Figure 1).

In this study, characteristic points of contours are automatically determined during the process of derivation of skeleton lines from contours in accordance with the method developed by *Aumann et al.* [1991].

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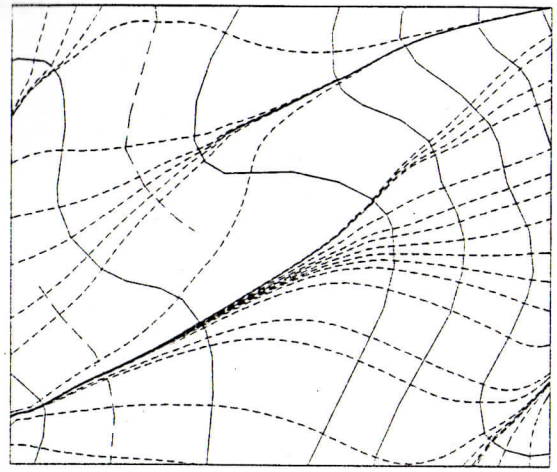


Figure 1: Contours, the steepest slope lines and the skeleton lines

2. DERIVATION OF SKELETON LINES FROM CONTOURS

In accordance with the method developed by *Aumann et al.* [1991] skeleton lines are derived from contours in two steps: Preparation and tracing processes.

2.1 Preparation Processes

Before starting of derivation of skeleton lines

- obtaining an optimum triangulated irregular network (TIN),
- determination of locations of skeleton lines in the TIN and
- determination of types of skeleton lines in the locations where the skeleton line exist

are necessary.

2.1.1 Obtaining an Optimum TIN

At this stage, the aim is to obtain a TIN, which has the following properties, by means of contour points and segments:

- Each contour segment is a triangle edge as well.
- Triangle edges do not cross each other.
- Triangle edges do not cross contour segments.
- Each triangle is an optimum triangle.

Such a TIN may be obtained by the method of constrained Delaunay triangulation in the best way.

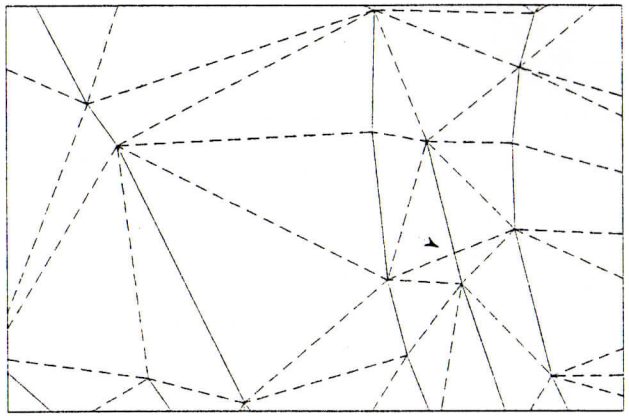


Figure 2: A triangle edge crossing a contour segment

2.1.2 Determination of the Locations of Skeleton Lines in the TIN

Horizontal triangles occur in such a TIN as described above. A horizontal triangle is the one three vertices of which have the same height. Horizontal triangles seem as if they occur because of the wrong or insufficient triangulation but they have important clues. Horizontal triangles occur where the skeleton lines most probably exist [*Aumann et al.*, 1991]. In other words horizontal triangles occur where the characteristics of the relief change (Figure 3 and 4).

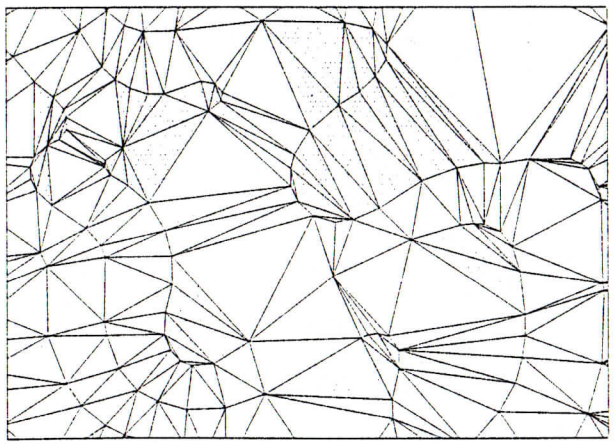


Figure 3: Horizontal triangles (dotted ones)

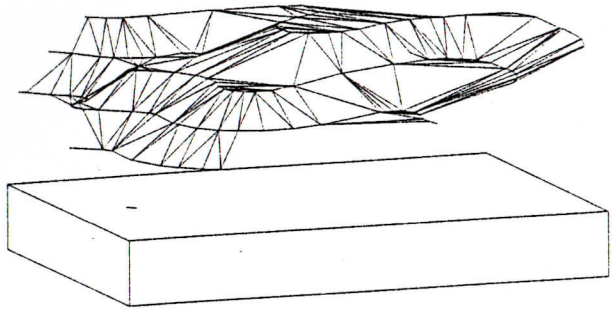


Figure 4: An appearance of the TIN from a viewpoint

2.1.3 Determination of the Types of Skeleton Lines

Types of skeleton lines are determined by means of the steepest slope vectors at the contour points. A steepest slope vector at a contour point is a bisector unit vector between the consecutive contour segments the common point of which is the contour point. The decision about the sides of the contours (i.e. higher or lower side of contours) where the bisectors are computed is made in advance and all bisectors are computed at the same side. For example, all bisectors are computed at lower sides of contours and the bisectors look at each other in the area where the skeleton line is computed. In this case, the skeleton line is a drainage line. The contrast of this situation is true for the ridge lines. In Figure 5, the steepest slope vectors at the sample contour points are shown.

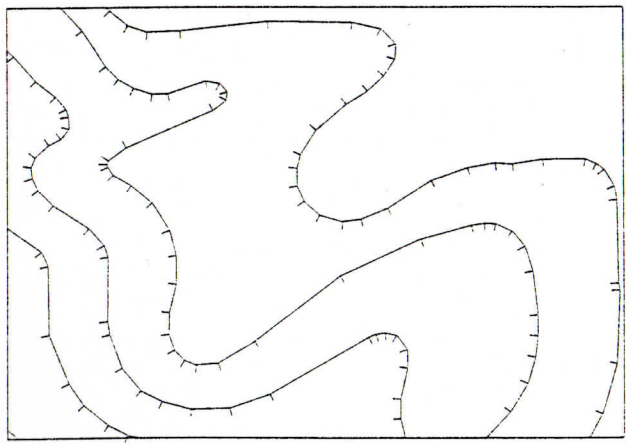


Figure 5: The steepest slope vectors on contour points

2.2 Tracing Process

Tracing process may be explained in the following example. Assume that a marble will be allowed to roll down at a point on the earth. If the earth surface is plain, the marble will roll down at only one direction. If not the marble will change its direction in accordance with the change of slope and roll down at different directions. The directions in both first and second situation have a common property. These are the steepest slope directions. In other words, a marble always rolls down at the steepest slope directions. This path being rolled down by the marble is called the steepest slope line in cartography, and computation of the path in the TIN based contours is called tracing process.

Some properties of the steepest slope lines are as follows:

- A steepest slope line may be traced all over the relief.
- Desired number and density of steepest slope lines may be traced.

If sufficient number and density of steepest slope lines are computed in the TIN with tracing process, the results are as follows:

- Some steepest slope lines come together at some parts of the TIN, and after going on together through those parts, they separate again (Figure 1).
- The parts of the TIN, where the steepest slope lines come together, are generally horizontal triangles in the TIN.
- The paths on which steepest slope lines go on together are overlapped with skeleton lines (Figure 1).

In this context, skeleton lines are the specific steepest slope lines whose locations are known. So, it is not necessary to trace too many steepest slope lines all over the relief as it is shown above. Skeleton lines may also be traced directly. This process is achieved in accordance with an algorithm developed in this study as follows.

The parts of the TIN, where the skeleton lines exist, are called *critical areas*. A critical area consists of a horizontal area or a series of consecutive horizontal areas. *A horizontal area* consists of a separate horizontal triangle or a series of neighbor horizontal triangles whose common edges are not on the contour.

A tracing process is started with selecting a contour point as a beginning point of a skeleton line which causes to get a steepest slope line that is the longest and whose slope is the smallest in the critical area. And, from this point, a series of unit vectors whose directions are the steepest slope directions, called skeleton line vector, are computed consecutively through the critical area. When reaching the end of the critical area or going into *a keeping in horizontal triangle* or *a last point triangle* or reaching the rim of the TIN, the tracing process is finished and thus a skeleton line is derived.

Beginning point of a skeleton line is selected in the highest or the lowest horizontal area of the critical area if the skeleton line is to be derived is a drainage or ridge line respectively.

Magnitude of a skeleton line vector (i.e. unit magnitude) is computed by Equation (1)

$$SL = 0.1 \times MP \quad (1)$$

Here, *MP* is the average of the lengths of the contour segments [*Aumann*, 1994].

Direction of a skeleton line vector is computed in the following steps:

1. Computation of the directions (i.e. the steepest slope directions) and the x, y components of the steepest slope vectors on the vertices of the triangle containing beginning point of the skeleton line vector.
2. Computation of the x, y components and the direction of the skeleton line vector by means of linear interpolation from the x, y components of the steepest slope vectors on the vertices of the triangle separately.

Directions of the steepest slope vectors on the vertices of the triangle containing beginning point of the skeleton line vector (i.e. the steepest slope directions on the vertices) are the bisectors on the contour points that are same as the vertices of the triangle.

A keeping in horizontal triangle is the one from which skeleton line vectors may not go out. Every skeleton line vector tracing on or inside a keeping in horizontal triangle joins together at a point. This point can be called *balance point* and at this point slopes in every directions are zero.

A last point triangle is a triangle one of whose vertices is one of the last points of an open contour. When computed skeleton line vector go into such a triangle tracing process is also finished automatically because it is not possible to compute the steepest slope vector (i.e. bisector unit vector) at the last points of the open contours. Last point triangles occur along the rim of the TIN and the ends of the secondary contour.

3. DETERMINATION OF CHARACTERISTIC POINTS OF CONTOURS

Characteristic points of contours are determined in two steps of a tracing process:

- Selecting of the beginning point of the skeleton line and
- crossing a contour segment by the last computed skeleton line vector.

In the first situation beginning point of the skeleton line, and in the second situation contour point that is nearer to the point at which the skeleton line vector crossed the contour segment is the characteristic point of the contour (Figure 6).

In Figure 7a and 7b, the results of a tracing process (i.e. a derived skeleton line and the characteristic points) are shown.

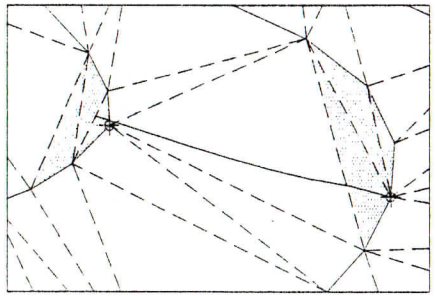
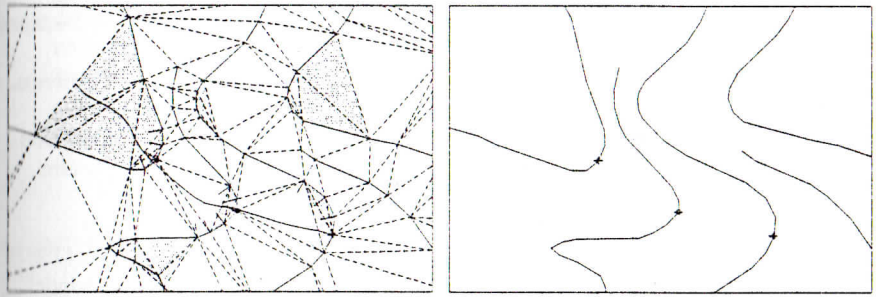


Figure 6: Characteristic points



(a) (b)

Figure 7: (a) Results of a tracing process (b) Contours and the characteristic points

4. CONCLUSIONS

In this approach, the method of derivation of skeleton lines developed by *Aumann et al.* [1991] in order to remove the horizontal triangles or artificial terraces in the TIN is used as a tool in determination of characteristic parts and points of contours. This approach is the only one that has bases of cartography and geomorphology in the issue of determination of characteristic points of contours.

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MULTI-EPOCH DEFORMATION ANALYSIS VIA VISION METROLOGY

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Automated, off-line vision metrology systems offer an ideal tool for 3D measurement within industrial manufacturing and large-scale engineering. One area of application, in which recent enhancements in vision-based measurement capabilities have led to wider application of this technology, is multi-epoch measurement for deformation analysis. This paper describes a deformation survey of the World's largest electric ring motor which was conducted using a high-precision vision metrology system. Following a brief overview of off-line vision metrology, the project requirements for the deformation monitoring are described and the photogrammetric measurement design is discussed. Results of the multi-epoch measuring sequence are then summarised and a brief account is given of the deformation analysis.

1. INTRODUCTION

Since the early days of development of high-precision close-range photogrammetry systems for industrial and engineering applications, the role of this measurement technology in deformation surveys has progressively expanded. Applications of photogrammetry for monitoring the deformation of engineering structures, manufactured assemblies and natural phenomena (e.g. landslides) have been extensively documented in the literature over the last decade and a half. Until the mid 1990s, the majority of photogrammetric deformation surveys were carried out using film-based systems. This trend continued even in the early stages of development of digital close-range photogrammetric systems, primarily due to accuracy shortcomings of CCD cameras at the time. Relatively recent advances in both on-line and real-time vision metrology (VM) systems, which have been brought about primarily through innovations in system automation and the introduction of large-area CCD cameras, have greatly enhanced the scope of such systems for complex, multi-epoch deformation measurement tasks. One such task, which forms the subject of this paper, has been the determination of structural deformation of what is reputed to be the World's largest electric ring motor, an ore concentrator/crusher at a gold mine in the State of New South Wales, Australia.

Figure 1 shows a photograph of the motor, taken during its construction. (This particular image was found in an advertisement which appeared in a Thai newspaper.) What is noteworthy in the figure, in the context of the multi-epoch deformation analysis conducted, is the rotor of the motor. The required structural monitoring centred on a determination of variations in the rotor-stator separation. The rotor itself is 15m in diameter, and when the stator (including housing) is included the overall diameter increases to 23m (see Figure 3).