EXTRACTION OF GEOLOGICAL LINEAMENTS FROM LANDSAT IMAGERY BY USING LOCAL VARIANCE AND GRADIENT TREND

S.R. XU, C.C. LI, N.K. FLINT

University of Pittsburgh
Pittsburgh, Pennsylvania

ABSTRACT

A method for computer extraction of geological lineaments from LANDSAT images is presented. The variance thresholded map of each image is separated into eight gradient direction maps. Where basic linear segments are determined each of which is based on the principal eigenvector of a cluster of pixels whose gradient direction is orthogonal to its orientation. A special linking algorithm operates on the basic linear segments to give a candidate lineament segment. The method has been experimented on LANDSAT images of a small region southwest to Pittsburgh. The preliminary result is encouraging and further work for improvement is suggested.

I. INTRODUCTION

Interpretation of lineaments from LANDSAT images has significant applications to geological studies. They may reflect structural features as surface manifestation of possible fractures and faults, and may be used to aid in the placement of geological measurements for exploration of petroleum/gas and mineral resources. Lineaments are usually situated in a highly textured image background. Some lineaments appear rather prominent while others subtle; their visual interpretation is often quite subjective. Linear enhancement and computer-aided extraction of lineaments have been studied by Podwysocki, et al. and Chavez, et al. A technique for digital enhancement by combining principal component analysis with multispectral classification was developed by Fontanel, et al. and applied by Hilali, et al. The performance of algorithms of linear, semilinear, and nonlinear detectors was examined, and an algorithm for iterative enhancement of linear features was developed by Vanderbrug. Match filters were used by Ehrich in preprocessing for automatic extraction of lineament segments which were then linked by means of dynamic programming. Recently, Jackson, et al. conducted an extensive study by various methods on computer enhancement of interpretative lineaments in the remotely sensed images of Cottageville, West Virginia, and developed a method of gradient filtering for enhancement of directional trends. All of these studies have been directed towards providing an improved capability of computer-aided interpretation of geological lineaments. This paper intends to present our progress in this area.

Lineaments are line-like features in a terrain. Along a lineament, the transverse changes in gray value persist, but its edge characteristics may vary. Hence, it must be perceived both locally and globally. Three characteristics of a lineament are noted: (1) within its small neighborhood, one side shows darker shade while the other side is brighter; (2) the variance of grayness in its small neighborhood is often large to account for the change in grayness across the lineament; and (3) the pixels along a lineament mostly have more or less the same gradient direction, although their directions may be reversed at some places, and their trend must continue for a significant length. These features are incorporated in our lineament model for algorithm development.
II. DETECTION OF BASIC LINEAR SEGMENTS

Each of the multispectral images under consideration is preprocessed first by level slicing to stretch its gray range to 256 levels. Consider a small nxn window (for example, n = 3) centered around each pixel (i,j), and compute its mean gray level \( \bar{G}_{ij} \) and its variance \( \sigma^2_{ij} \) within the window. These local statistics may be used for contrast enhancement and noise filtering.\(^{14}\) By choosing an appropriate threshold value \( \sigma_c \) of the local variance, a region of high nonhomogeneity is segmented by locating those pixels whose local variance \( \sigma^2_{ij} \) is greater than \( \sigma_c \). Within such a variance thresholded map, the narrow region around a lineament segment is expected to lie. The local variance parameter has also been used in processing SEASAT SAR images for classifying statistically homogeneous subregions in the polar ice region.\(^{15}\) From the pool of pixels in the variance thresholded map, their gradient directions are examined for possible trends of lineament segments.

For those pixels which exist in the variance thresholded map, their Sobel gradients are evaluated. Each of these pixels, \((i,j)\), and its 3x3 neighbors in the image are convolved by operators \( H_1 \) and \( H_2 \) to give the horizontal and vertical differences \((i,j)\), respectively. Both the magnitude and direction of the Sobel gradient \( S(i,j) \) are computed. The gradient direction is quantized into eight direction numbers \((0,1,2,\ldots,7)\), with 0 direction pointing to the east and 1 direction pointing to the northeast, etc. Each pixel in the variance thresholded map may then be labeled by its direction code. Eight gradient direction maps are then separated, each of which represents those pixels whose gradient directions are \( q \) coded by the same number \( q \). (\( q = 0,1,2,\ldots,7 \)). Search is then attempted in each direction map to obtain pixels forming possible linear segments with a direction orthogonal to the gradient direction of the map.

Consider a square window of \( mxm \) pixels (\( m = 32 \) in this study) in a direction map with direction \( q \). Examine the number and distribution of pixels in the window, and evaluate eigen values \( (\lambda_1 \text{ and } \lambda_2) \) and eigen vectors \( (e_1 \text{ and } e_2) \) of this cluster of pixels. If there exists a single cluster of contiguous pixels which are aligned linearly with a direction orthogonal to the gradient direction \( q \), these pixels naturally form a segment of a possible lineament. If a cluster of sufficient number of pixels, not necessarily contiguous, is significantly elongated, the principal eigen vector \( e_1 \) passing through the cluster center may be an adequate representation of a linear segment. Let \( N \) be the number of pixels in the cluster in a window, and \( r = A_1/A_2 \) be the ratio of eigen values of the cluster. If \( N \) and \( r \) are greater than their respective threshold values \( N_c \) and \( r_c \), and furthermore, if the direction of its principal eigen vector is orthogonal to the gradient direction within \( \pm 22.5^\circ \) tolerance, this eigen vector extending between two sides of the square window, as shown in Figure 1, is accepted as a basic linear segment. The lineament is now not restricted to a quantized direction. The use of the cluster eigen vector permits us to detect a possible lineament segment even when it is interrupted in the middle as long as the gradient directions of the pixels are consistent so as to provide a lineament trend.

This process is repeated in all successive windows in a given direction map and for all directions to detect all basic linear segments in an image. It should be noted that any two successive windows are overlapped by \( 0.5 \) horizontally or vertically in order to take care of the cases where a cluster may be split by a window into two small parts below the threshold size.

III. LINKING OF BASIC LINEAR SEGMENTS

The process of linking basic linear segments should be viewed as a means of approximation. It is not often to find two basic linear segments which are precisely aligned or which can be connected from end to end. Thus, the linking of two neighboring segments is achieved by connecting their respective cluster centers to provide a piecewise linear approximation.

For a basic linear segment \( L_k \) in "window k", search is made to link it with another basic linear segment, if exists, in one of its three neighboring windows. Depending upon whether the orientation of \( L_k \) is closer to the vertical, horizontal, or diagonal direction, the three neighboring windows are specified by "window k+1", "window k+2" and "window k+3" as shown in Figure 2 (a),
(b) and (c); and they are searched in that order. If a basic linear segment $L_{k+1}$ exists in "window $k+1"$ and if the difference in orientation between $L_k$ and $L_{k+1}$ is less than $45^\circ$, they are allowed to be linked together by connecting their respective cluster centers $C_k$ and $C_{k+1}$ as illustrated in Figure 3. Otherwise, their directions are inconsistent, so $L_{k+1}$ should not be linked to $L_k$. If there is no basic linear segment in "windows $k+1$, $k+2$ and $k+3"$, which can be connected to $L_k$, the next set of three windows should be searched as indicated by "window $k+4", "window k+5" and "window k+6" in Figure 2 (d), (e) and (f). If the search is successful, the current linking process can be continued forward; otherwise, the process stops at $L_k$ and a new linking effort will start at another window. As shown in Figure 3, the successful linking of a series of basic linear segments provides an extended piecewise linear structure following a trend which is orthogonal to the average gradient direction of the pixels on the line. In this way, candidate lineaments are extracted from those pixels having the similar gradient direction and being not too far separated even though not contiguous.

IV. EXPERIMENTAL RESULTS

A portion of LANDSAT-1 image of a region southwest to Pittsburgh has been experimented by the above-described method. The images from four spectral bands are shown in Figure 4 (a), (b), (c) and (d). Each image is of $512 \times 1024$ size. A lineament map in this region as viewed by two geologists is shown in Figure 5. A total of 28 lineaments were mapped.

Only one half on each image consisting of $512 \times 512$ pixels was processed at a time; the results were then combined. The variance threshold $\sigma$ for each image was chosen as that value of $\sigma$ such that the upper 10% under the variance histogram was covered for $\sigma > \sigma_t$. In the detection of basic linear segments, two sets of threshold parameters $N_t$ and $r_t$ were used. If $N > N_t = 32$, then $r > r_t = 1.5$. If $32 \geq N \geq 16$, then $r > r_t = 8$. The length of the basic linear segments varied between 16 pixels and 128 pixels, corresponding to the actual length of approximately 1 to 2 km.

The processing results obtained for the images of all 4 spectral bands are shown in Figure 6 (a), (b), (c) and (d). Combining these results, 13 segments of lineaments were extracted by this method. Many spurious short linear segments were found, which were not true lineament segments.

V. DISCUSSIONS

It is apparent that the experimental result gave a considerable amount of error in the automatic detection of lineaments. A close examination suggested several problems for further consideration. Long lineaments were not fully traced by computer processing because the thresholded variance maps failed to provide sufficient regions for extraction of basic linear segments. A more refined preprocessing should be performed in order to improve the detection accuracy. A larger window (for example, $64 \times 64$ pixels) and separate cluster seeking may be preferred for more reliable identification of basic linear segments. A more global trend search should be further developed to identify the possible alignment of several linear segments which are separated far apart. Some of the spurious short segments may then be discarded as they individually do not fit into a longer trend. These aspects are being presently investigated for further improvement.

VI. REFERENCES


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A cluster of pixels whose gradient direction is q

32x32 window

Cluster center

Principal eigenvector with orientation orthogonal to the gradient direction q

Figure 1 - Basic linear segment determined by the principal eigenvector of a cluster of pixels in a gradient direction map.
Figure 2 - Neighbouring windows of "window k" specified in search for connection of basic linear segments.

Figure 3 - Linking a series of basic linear segments
Figure 4 - LANDSAT-1 images of a region southwest to Pittsburgh, PA.
Figure 4 - (Continued)
Figure 5 - A lineament map determined by two geologists for a region defined in Figure 4.
Figure 6 - Lineaments extracted by computer processing.
Figure 6 - (Continued)
S. R. Xu graduated from the Electrical Engineering Department, Zhejiang University, Hangzhou, Zhejiang, China in 1962. After graduation, he has stayed on as a faculty member, and has become a lecturer in the Radio Engineering Department at Zhejiang University since 1978. He has done research on DPCM, 15-channel timer, adaptive synthetic highs coding for color television data compression, and digital image processing and pattern recognition. He has been a visiting scholar at the Department of Electrical Engineering, University of Pittsburgh since March 1980, and will be a visiting scholar with Purdue University for one year beginning July 1981.

Ching-Chung Li received B.S.E.E. degree from National Taiwan University, Taipei, China in 1954, M.S.E.E. and Ph.D. degrees from Northwestern University in 1956 and 1961 respectively. After graduation, he has joined the faculty of Electrical Engineering at the University of Pittsburgh. He was a junior engineer at Westinghouse Electric Corporation in Summer 1957, a Visiting Associate Professor at University of California, Berkeley, January - June 1964, and a Visiting Principal Scientist at Alza Corporation, Palo Alto, California, May - August 1970. Presently, he is a Professor of Electrical Engineering and Professor of Computer Science at the University of Pittsburgh. He is a Fellow of IEEE, and a member of the Technical Committee on Pattern Analysis and Machine Intelligence of IEEE Computer Society.

N. E. Flint received A.B. degree from University of New Hampshire in 1944, M.S. and Ph.D. degrees in geology from the Ohio State University in 1946 and 1948 respectively. He has taught at Ohio State University, University of Pittsburgh, and Central University of Ecuador, and has been a Professor of Geology in the Department of Earth and Planetary Science at the University of Pittsburgh since 1969. He is a Fellow of Geological Society of America, and a Past President of Pittsburgh Section of the American Institute of Mining, Metallurgical, and Petroleum Engineers.