EVALUATION OF LINEAMENT DETECTION ALGORITHMS USING MULTI-BAND REMOTE SENSING IMAGES

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ABSTRACT

This paper presents a lineament detection method using multi-band remote sensing images. A Linear feature Network Detection and Analysis system - LINDA has been applied to multispectral satellite data such as Landsat TM images in the Canadian shield area of northern Ontario. The proposed technique involves the following steps: Preprocessing, Edge detection, Multi-band combination and Hough Transform. The results demonstrate that the proposed multi-band lineament detection procedure achieves better performance in comparison with the existing single-band algorithms.

INTRODUCTION

Lineaments are linear topographical or tonal features on the terrain representing zones of structural weakness (Williams, 1983). They may be recognized on and interpreted from images and maps. Identification and mapping of lineaments from satellite images is an important use of remote sensing data in many geologic applications. On satellite images, lineaments usually appear as straight lines or edges, but frequently a lineament may have gaps in it due to poor contrast of the lineament with its surroundings or coverage of surface materials. In visual interpretation and mapping of lineaments, geologists use their knowledge and experience to connect lines and edges which are collinear and broken into a series of segments. It is suggested that some of the "rules" that are used by geologists in their image interpretation can be applied in automated lineament extraction from digital imagery. This paper presents a lineament detection method using multi-band remote sensing images. A Linear feature Network Detection and Analysis system - LINDA (Wang, 1993) has been applied to multispectral satellite data such as Landsat TM images in the Canadian shield area of northern Ontario.

METHODOLOGY

The proposed technique involves the following steps:

Preprocessing

For the majority of images, it is important to apply a filter to the image to smooth it and remove most of the noise. If this were not done, problems of isolating individual lineaments would occur later in the analysis. In this study, a median filter was applied to the original data.

Multi-band combination

As opposed to most existing lineament detection methods, which use single-band images only, the proposed method is designed to operate on several channels and combine different linear feature information. Principal Component Analysis (PCA), band ratioing, and their combination are applied to the filtered channels. The resultant channel contains edge information from multiple original channels.

Edge Following as Graph Searching

In this stage, Edge Following as Graph Searching (EFGS) algorithms (Wang and Howarth, 1987, 1989; Wang, 1993) are applied to the combined channel to identify edges in the image. This involves three major steps. First, an "edge operator" is used to obtain the magnitude and direction of an edge. This is based upon determining the locations where maximum changes in digital values occur and what the directions of these changes are. The procedure can be applied to detect edges as well as light lines or dark lines, depending upon the appearance of the lineaments in the image. Second, the starting points for the edges are identified. The starting edge point selection algorithm identifies the most prominent edges and it is found that a large number of these correspond to parts of lineaments. Finally, EFGS is used to trace all the edges on the image. A graph can be formed from each starting edge point. Each arc in the searching graph is associated with a cost. The cost is a function of edge magnitude and direction, as well as the tracing direction. The EFGS algorithm may be summarized as follows:

(1) Accept all starting points as edge elements.

(2) If there are no more starting points, stop. Otherwise, assign the next starting point as the current node.

(3) If there is no neighbor in front of the tracing direction of the current node, go to Step (2).

(4) Compute the cost for the arc connecting the current node to each of its neighbors in the tracing direction. Accept the minimum cost neighbor as an edge element. If no neighbor is accepted, go to Step (2). Otherwise, assign this neighbor as the next current node and the direction of the arc from the previous current node to this node as its tracing direction. Go to Step (4).

Hough Transform

The edge image obtained from the EFGS algorithms contains edge pixels with a value of 1 and background pixels with a value of 0. The problem in lineament detection is to locate the presence of groups of collinear or almost collinear edge pixels. The problem can be solved to any desired degree of accuracy by testing the lines formed by all pairs of points in the picture. However, the computation required for n pixels is approximately proportional to n^2, and may be prohibitive where n is large. Hough (1962) proposed an interesting and computationally efficient procedure for detecting lines in pictures. It has become known as the Hough Transform. The main advantages of the Hough Transform are that it is relatively unaffected by gaps in lines and by noise. In this paper, Hough Transform is applied to detect straight lines which represent geologic lineaments on the multispectral satellite images. The Hough Transform method described by Duda and Hart (1972) is used and modified for lineament detection. The procedure involves use of the Hough Transform, finding of local maxima, application of an inverse Hough Transform and straight line profile analysis (Wang and Howarth, 1990). Geological lineaments are frequently discontinuous on the original image. However, the segments lying on the same line can be joined together if they are close enough to each other. In other words, certain gaps are allowed on a line in this straight line detection algorithm. The size of the gaps allowed for can be assigned by the user of the LINDA system (Wang, 1993).

RESULTS

To evaluate the performances of the lineament detection algorithms on multi-band remote sensing images versus on single band images, a study area of part of the Canadian Shield near Sudbury, Ontario has been selected. It includes part of the exposed Grenville Province. The dominant rocks in this area are middle Precambrian metasediments and an anorthosite suite of intrusive rocks. Structural control is suggested by the preponderance of elongate lakes confined to a few orientations. A subscene of a Landsat 5 Thematic Mapper (TM) image with seven channels over the study area is obtained.
The procedure for lineament detection, including preprocessing, edge detection and Hough transform, has been applied to each of the seven Landsat TM channels. From a comparison of all the seven TM bands, it is observed that Band 4 image (near infrared) displays the lineaments most clearly (shown in Figure 1) and that Band 4 image also results in the best single-channel lineament detection (shown in Figure 2) among all seven Landsat TM bands. However, from Figure 2, it can be seen that not all lineaments are detected.

To improve the lineament detection, multiple bands are used instead of single bands. Since each band collects different spectral information of the same ground scene, it may highlight different parts of linear features. Experiments are carried out to combine multiple band information, such as Principle Component Analysis and Band Ratioing. Figure 3 shows the lineament detection resulted from the first eigen channel of the Principle Component Analysis of all TM bands except Band 6. Figure 4 displays the lineament detection resulted from ratioing of Band 4 over Band 3. These resultant lineament maps can also be overlaid or further combined, as shown in Figure 5. Visual interpretation of the subimage was performed by experienced geologists. Visual examination of Figures 2, 3, 4 and 5 against the visual interpretation result indicates that all three multi-band lineament maps provide better results than the single-band lineament map (in Figure 2). Among the three multi-band lineament maps, the overlay of PCA-1 and Ratio4/3, as shown in Figure 5, detects the most lineaments.

To summarize, it has been demonstrated that it is possible to develop algorithms to extract lineament information from Landsat TM imagery of the Canadian Shield. The comparison of single-channel and multi-channel lineament detection shows that the best multi-band detection achieves better results than the best single-channel detection. This demonstrated the potential of multi-spectral edge detection techniques and their applications in linear feature identification.

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Figure 1 A subscene of a Landsat 5 TM Band 4 image over the study area.

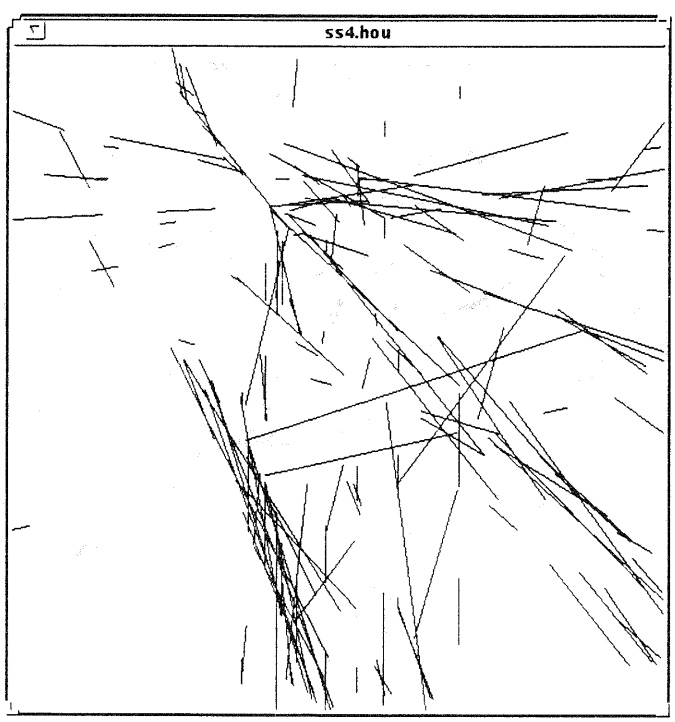

Figure 2 The best single-channel lineament detection resulted from Figure 1.

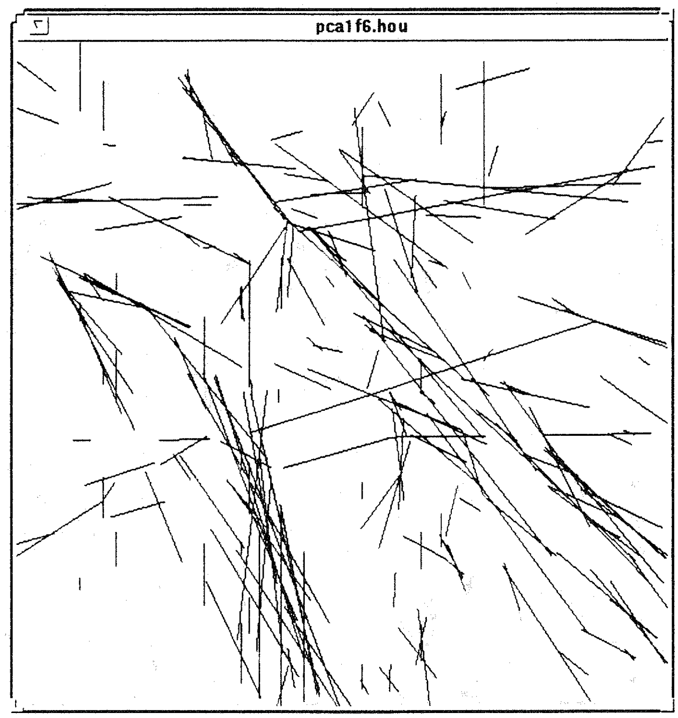

Figure 3 Lineament detection resulted from the first eigen channel of Principle Component Analysis of all TM bands except Band 6.

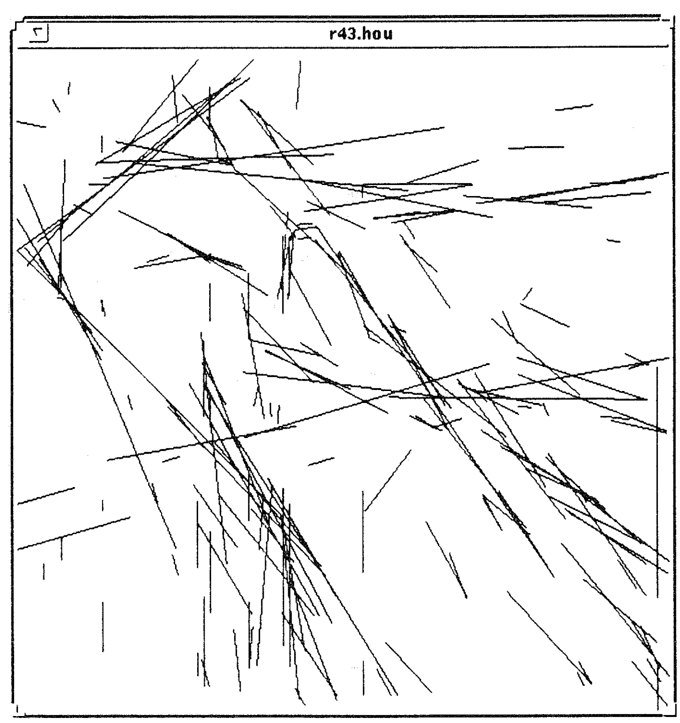

Figure 4 Lineament detection resulted from ratioing of Band 4 over Band 3.

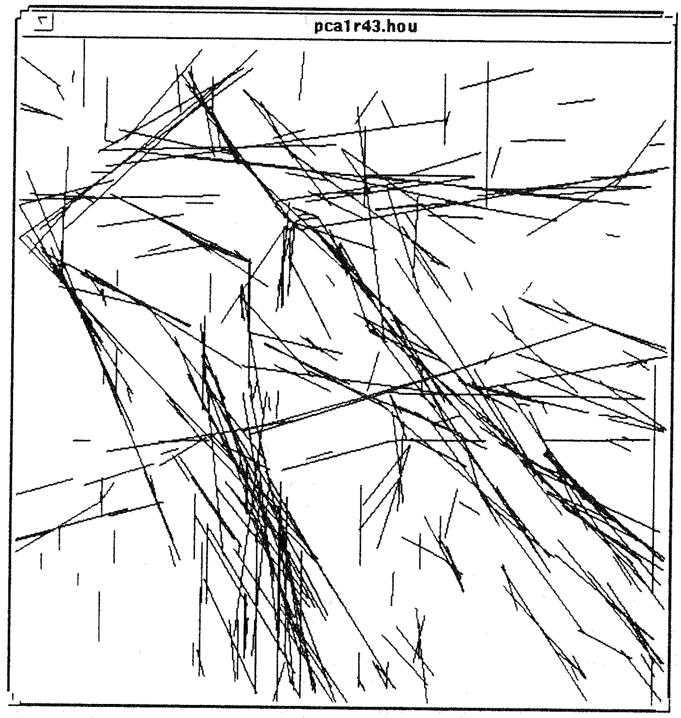

Figure 5 Binary overlay of Figure 3 and Figure 4.