

Reprinted from

Seventh International Symposium

Machine Processing of

Remotely Sensed Data

with special emphasis on

Range, Forest and Wetlands Assessment

June 23 - 26, 1981

Proceedings

Purdue University
The Laboratory for Applications of Remote Sensing
West Lafayette, Indiana 47907 USA

Copyright © 1981

by Purdue Research Foundation, West Lafayette, Indiana 47907. All Rights Reserved.

This paper is provided for personal educational use only,
under permission from Purdue Research Foundation.

Purdue Research Foundation

A LINEAMENT ENHANCEMENT TECHNIQUE FOR ACTIVE FAULT ANALYSIS

HIROYASU TAKAHASHI

IBM Japan
Tokyo, Japan

ABSTRACT

Lineament enhancement is an important subject in image processing. In this paper a simple but powerful lineament enhancement technique is presented, which consists of a unique differentiation and a directional filtering. A preprocessing and postprocessings are also described. And some results from LANDSAT images are selected and exhibited for comparison of the effects of several parameters in each step.

I. INTRODUCTION

The detection of active faults is indispensable for earthquake researches and resource explorations. It is generally carried out by on-the-spot surveys or interpretation of airphotos by the eye. Besides these methods, LANDSAT images are utilized. These images have some merits: wide coverage of survey area, easiness of acquisition of digitized images in magnetic tapes, etc. The analysis of active faults by LANDSAT images is mainly done by the eye, and the machine processing of them is still in an early stage. If the machine processing could produce good results, it would give us valuable profits, e.g., exclusion of subjectivity by analysts, release from voluminous works, etc.

Direct machine processing of active faults is very difficult, so lineaments are generally taken as the target in place of them, which are line-like features in the terrain that are inferred to be faults or joints. The term 'lineament' is used here in a broad sense. Vanderbrug¹ proposed semilinear line detectors and applied them to satellite imagery. Phrich² developed a global edge detection method, which adopted matched filtering, directional average functions, a heuristic peak

finder, and a global line constructor. Here, a new lineament enhancement technique, simple but powerful one, is described.

II. LINEAMENT ENHANCEMENT

The most remarkable feature of lineaments can be assumed to be linear edges. With attention to this feature, the technique consists of two main steps, STEP 1 and STEP 2. STEP 1 makes an edge image from an original image by running a unique filter that adopts differentiation under increase condition and an upper limit for big values. STEP 2 applies a directional filtering that rotates a thin slit around every pixel in the differential image and calculates the average value in the slit. Through these steps, linear edges are enhanced.

Generally STEP 1 and STEP 2 are executed for 2 or 4 directions to eliminate the inequality by the differentiation under increase condition, and then the lineament enhanced images are overlaid by the maximum value for every pixel.

Furthermore, when even treatment is desired for lineaments in terms of strength of contrast, a dynamic contrast stretching is performed to the original image before STEP 1. This will be called Step 0 for convenience. The results from STEP 2 are made of gray values, so when enhanced linear lines should be decided to be there or not, some more processings are required. In that case, thinning (Step 3) and line tracking (Step 4) are also applied to the results from STEP 2.

Note that STEP 1 and STEP 2 are main theme in this paper and that the results from STEP 2 are judged by the eye and mainly used for active fault analysis.

A. STEP 1

Lineaments often have two opposite contrast edges on their both sides, and one of the two has a noisy effect on the other in STEP 2. Also linear edges generally have bad effects on their neighboring linear edges in STEP 2, so independent processings of linear edges for different directions are desired. If the edges on the both sides are processed independently and overlaid, the other side has no effect on the averaging in STEP 2 and sharper edges can be obtained. Here, differentiation under increase condition is thought out and adopted to eliminate the effect on the other side and neighbors.

Fig.1 shows a pair of 5x5 differential windows under increase condition that is mainly used in this paper. Let's call the pair NW-filter (from north and west), which takes the maximum value of the two and aims to catch linear edges that have lighter portion on N,W,NW,NE, and SW sides (N:north, S:south, W:west, F:east). The / and X elements in the windows are ignored. The reason why four elements indicated by X are ignored is that if the filter encounters an oblique edge, two of them will have the opposite effect to the other elements in the window.

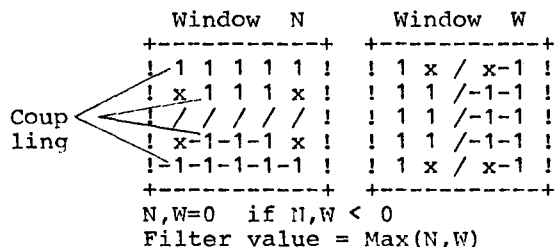


Fig.1 A sample of filters in STEP 1

In Fig.1, each positive window element is coupled to the opposite negative element and an upper limit for big difference of the couple is adopted so that the big value may not have an excessive influence on their neighbors in STEP 2. If the limit is set to the whole window instead of the couple, a few big values may still have a bad influence.

The parameters used in this step are as follows. The abbreviations will be used in section III for convenience.

- FLT: direction and size of the filter, e.g., NW5,
- LMT: upper limit for the difference between the pair,
- ABS: differentiation under increase

condition (NO), differentiation taking absolute values (YES).

B. STEP 2

The differential image from STEP 1 has useless minute edges and the candidates of lineaments often have gaps in themselves. To eliminate the minute edges and fill up the gaps, directional filtering is applied. It rotates a thin slit around every pixel in the differential image, calculates average values for every direction, and assigns the maximum value of all directions to the pixel.

Just when the pixel is on a lineament and the direction of the slit matches with the direction of the lineament, most of the values in the slit are big and the average value of the slit consequently becomes big and the maximum of all directions. In other words, pixels on linear edges have the chance to become big at least once, but the other pixels have no chance. Similarly small gaps in lineaments can have the chance and be filled up. Thus, linear edges are enhanced and smoothed and minute edges are vanished through this step.

The length of the slit is selected according to the length of lineaments of interest. The number of directions is decided according to the slit length and filter size in STEP 1, i.e., it is increased when the slit length is long and filter size is small. While the sampling interval in the slit is set in order to save computing time.

The parameters used in this step are as follows.

- LNG: length of the slit in directional filtering,
- DRC: number of slit directions for 180 degrees,
- INT: sampling interval in the slit.

C. OTHER STEPS

The following steps are executed only when preprocessing or postprocessings are desired.

Step 0. Lineaments are often manifested by weak edges compared with the global geological features such as peaks of mountains or valleys that are mostly different from lineaments. The strong edges other than lineaments are undesirable in STEP 2, because the weak lineaments diminish relatively. In order to decrease the undesirable effect of the above strong

edges, a dynamic contrast stretching method was developed. It controls global contrast and local one. When global contrast is weak and local contrast is strong, the difference between weak edges and strong edges becomes small.

Step 3. The results from STEP 2 have gray values and it is impossible for the machine to discriminate linear lines from their background. If further machine processings are desired to extract lineaments, the image should be binarized and thinned. The thinning algorithm by Hilditch³ is used here.

Step 4. The results from Step 3 have lineaments and also short or nonlinear lines that are out of interest in terms of lineaments. This step picks up lines that satisfy several conditions and are assumed to be candidates for lineaments. First, each edge point is searched and then the line is tracked. During this process, the line is assumed to reach its end when it goes out of the limit for linear line or it reaches another edge. After reaching the end, the line length is checked and it is assumed as a candidate for lineaments when the length is greater than a shorter limit.

III. EXPERIMENTS ON LANDSAT IMAGERY

In this section, some results are selected and exhibited for comparison of the effect of the parameters described in section II. The relation of the exhibited images is summarized in Fig.2. The (→) denotes processing flow. The comparison of two figures connected by (←→) will be explained below.

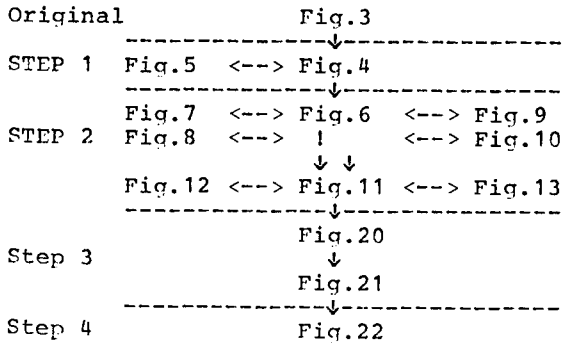


Fig.2 The relation of exhibited images in Yokoyama district

A. LINEAMENT ENHANCEMENT (STEP 1,2)

Original image. Fig.3 shows a LANDSAT

original image (Band 6, 240x256) in Yokoyama district that lies to the north-east of Lake Biwa. The area in the image has eight active faults, which are indicated by (→ ←→), after the Research Group for Active Faults⁴.

STEP 1. Fig.4 shows the differential image by applying the filter (FLT=NW5, ABS=NO, LMT=15) explained in Fig.1 to the original image. For comparison, Fig.5 shows the differential image by applying the filter (FLT=NSWE5, ABS=YES, LMT=15). The differential image under increase condition seems to display linear edges clearer than the other. This will later prove to be effective for lineament enhancement.

Upper limit. Fig.6 shows the lineament enhanced image of Fig.4 by the parameters (LNG=21, DRC=16, INT=1). Comparing this with Fig.7 (FLT=NW5, ABS=NO, LMT=255; STEP 2 same as Fig.6), the effect of the upper limit is obvious. Take the bottom right corner for example where a cloud is found, the big differential value between the cloud and land has a bad effect and ameba like portion far from linear line can be seen in Fig.7.

Filter size. Fig.8 shows a lineament enhanced image (FLT=NW3, ABS=NO, LMT=15; LNG=21, DRC=24, INT=1). The 3x3 filter is more sensitive for delicate edges than the 5x5 filter. The size of filter should be selected according to the lineaments of interest.

Slit length. Fig.9 and Fig.10 show lineament enhanced images (STEP 1 same as Fig.4; LNG=11, DRC=8, INT=1, LNG=41, DRC=32, INT=2, respectively). Comparing Fig.9 and Fig.10 with Fig.6, it is obvious that when longer slit is selected in STEP 2, the difference between long edges and short edges is emphasized and short edges diminish relatively.

Independent process for directions. Fig.11 shows an overlaid image by four lineament enhanced images (ABS=NO, LMT=15, FLT=NW5, NE5, SW5, SE5; STEP 2 same as Fig.6) On the other hand, Fig.12 shows a lineament enhanced image (ABS=YES, LMT=15, FLT=NSWE5; STEP 2 same as Fig.6). It is obvious that clearer linear edges can be obtained by the differentiation under increase condition and its independence for directions.

Number of overlays. Comparing Fig.13 (FLT=NW5, SE5), an overlaid image, with Fig.11 (FLT=NW5, SE5, NE5, SW5), they are

nearly similar. Although the latter type images are ideal, the former type images are often used to save computing time.

Texture by linear lines. Fig.14 shows a LANDSAT original image that displays the famous Atera fault in Japan which is indicated by (--> <--). On the other hand, Fig.15 shows the lineament enhanced image of Fig.14. It is very interesting that a linear line itself does not appear on the fault but the textures of linear lines on both sides of it are quite different and a lot of linear lines are cut off on the fault.

B. CONTRAST STRETCHING (Step 0)

Fig.16 shows a LANDSAT original image of desert area in Africa. Fig.17 shows the contrast stretched image by applying Step 0 to Fig.16. By this stretching, local delicate contrasts appear and the effect for lineament enhancement is observed in Fig.18 and Fig.19 that are lineament enhanced images of Fig.16 and Fig.17 respectively.

C. THINNING AND LINE TRACKING (Step 3,4)

Fig.20 shows the binarized image of Fig.11 by applying thresholding at about 90 % point of histogram. Fig.21 is obtained by applying thinning to the binarized image. Fig.22 shows the line tracked image by applying Step 4 to Fig.21. By this process, short or nonlinear edges are vanished.

IV. DISCUSSION

By applying this technique (STEP 1 + STEP 2) to LANDSAT images where many active faults were found and interpreting these by the eye, interesting results were obtained. Some enhanced lineaments coincided with the active faults on the fault map, e.g., in Fig.3, five out of eight active faults were indicated by enhanced lineaments. And some others that were not linear lines themselves but had different textures on their both sides also coincided with the active faults. Comparing the lineament enhanced image with the original one, some sensible lineaments disappeared but some linear lines appeared that were difficult to sense by the eye. Some of the newly appeared linear lines were checked by the use of stereo airphotos, and it seemed necessary to survey on-the-spot whether some of them were active faults or not.

There seems to exist much room for

improvement in this technique. For example, STEP 1 adopts only linear edges as a feature of lineaments, but many other features will be able to be involved in it. The algorithm of Step 4 is primitive one and will be easily improved by involving some functions such as smoothing and connection of lines.

V. CONCLUSION

The lineament enhancement technique developed here proved powerful in spite of the simple algorithm by experiments on LANDSAT imagery. Lineament enhanced image has some merits in comparison with the original image: it shows some linear lines difficult to detect in the original image; it can exclude subjectivity by analysts to a certain extent; it can release people from voluminous works, so it may be helpful for the active fault analysis. When resources permit, all the good points of judgements by the eye and machine processings should be utilized.

ACKNOWLEDGMENT

The author wishes to thank Assoc. Prof. T. Matsuda and other staffs of Earthquake Research Institute of Tokyo University for their useful suggestion on geology. He also expresses thanks to his colleagues, Mr. S. Uno for his useful discussion and Mr. J. Iisaka for his comment.

REFERENCES

1. Vanderbrug, G. J., 'Line Detection in Satellite Imagery', IEEE Transactions on Geoscience Electronics, vol. GE-14, no.1, pp.37-44, 1976.
2. Ehrlich, R. W., 'Detection of Global Edges in Textured Images', IEEE Transactions on Computers, vol. c-26, no. 6, 1977.
3. Hilditch, C. J., 'Linear Skelton from Square Cupboards', In Machine Intelligence 6, B. Melzer & D. Michie, Eds., Univ. Press, Edinburgh, pp. 403-420, 1969.
4. Research Group for Active Faults, Active Faults in Japan - sheet maps and inventories, Univ. Press, Tokyo, 1980.

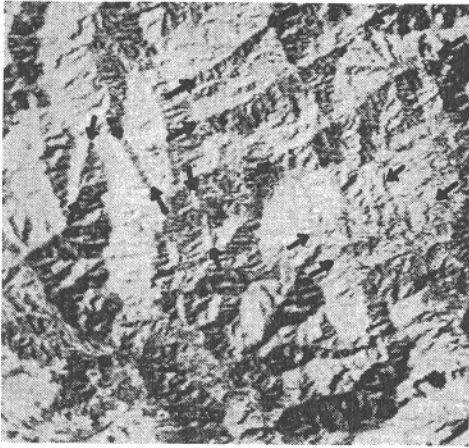


Fig. 3 LANDSAT original image in Yokoyama district (Band 6). Active faults are indicated by (---> <---).

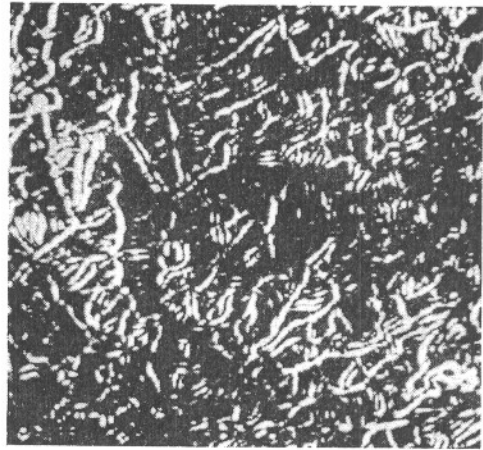


Fig. 5 Differential image by STEP 1 (FLT=NSWE5, ABS=YES, LMT=15).

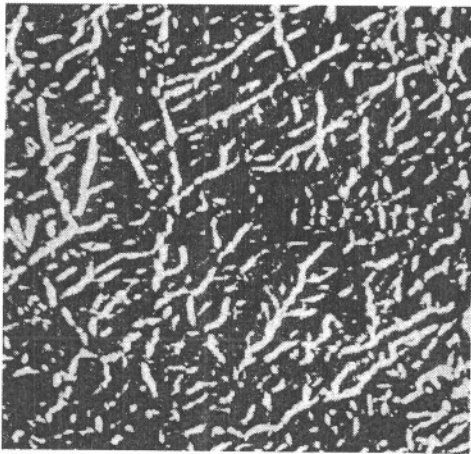


Fig. 4 Differential image by STEP 1 (FLT=NW5, ABS=NO, LMT=15).

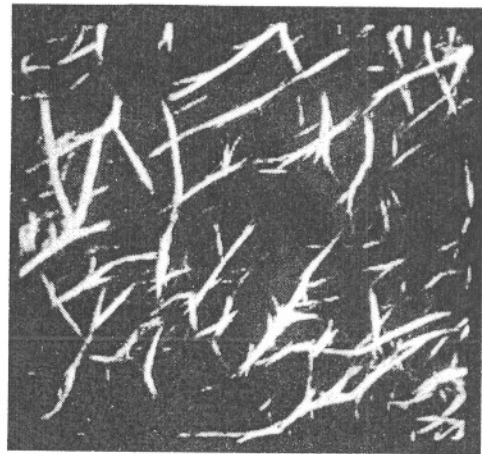


Fig. 6 Lineament enhanced image of Fig. 4 by STEP 2 (LNG=21, DRC=16, INT=1).

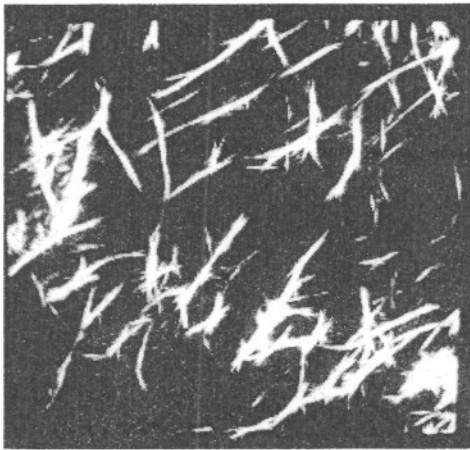


Fig.7 Lineament enhanced image (FLT=NW5, ABS=NO, LMT=255; STEP 2 same as Fig.6).

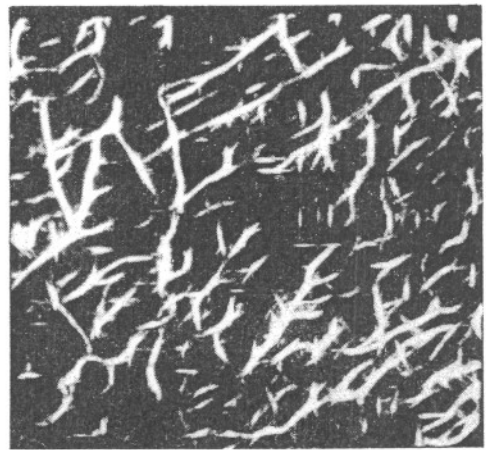


Fig.9 Lineament enhanced image (STEP 1 same as Fig.4; LNG=11, DRC=8, INT=1).



Fig.8 Lineament enhanced image (FLT=NW3, ABS=NO, LMT=15; LNG=21, DRC=24, INT=1).

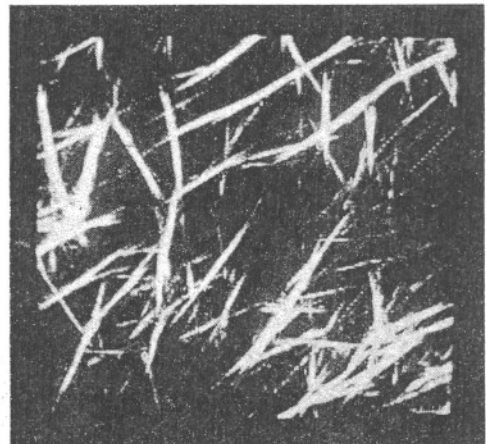


Fig.10 Lineament enhanced image (STEP 1 same as Fig.4; LNG=41, DRC=32, INT=2).

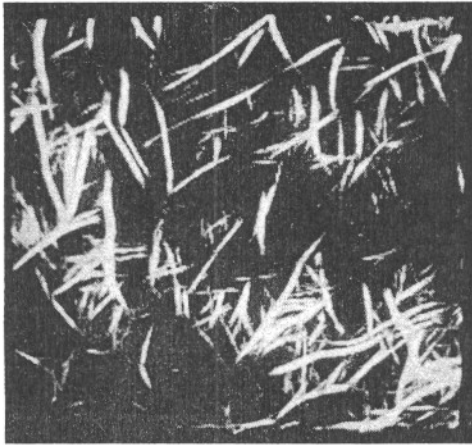


Fig.11 Overlaid image (ABS=NO, LMT=15, FLT=NW5,NF5,SW5,SE5; STEP 2 same as Fig.6).

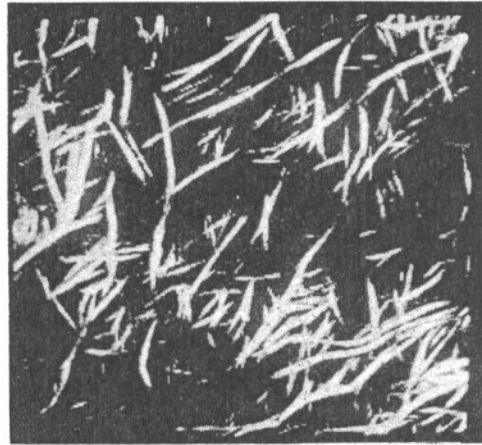


Fig.13 Overlaid image (ABS=NO, LMT=15, FLT = NW5,SE5; STEP 2 same as Fig.6).

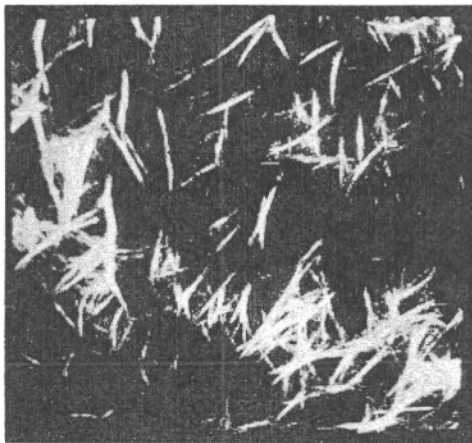


Fig.12 Lineament enhanced image (LMT=15, ABS=YES, FLT=NSWE5; STEP 2 same as Fig.6).



Fig.14 LANDSAT original image of the Atera fault (Band 6). the fault is indicated by (--> <--).

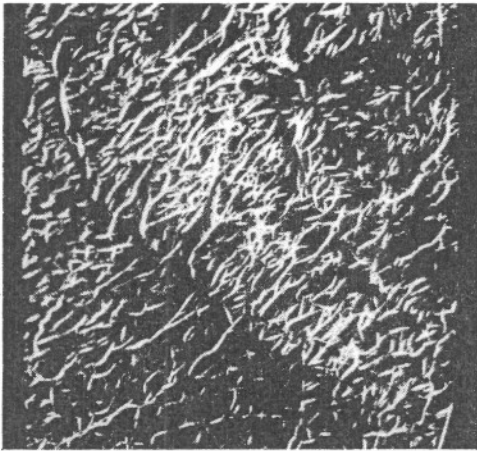


Fig.15 Lineament enhanced image of Fig. 14 (STEP 1 same as Fig.4; STEP 2 same as Fig.6).

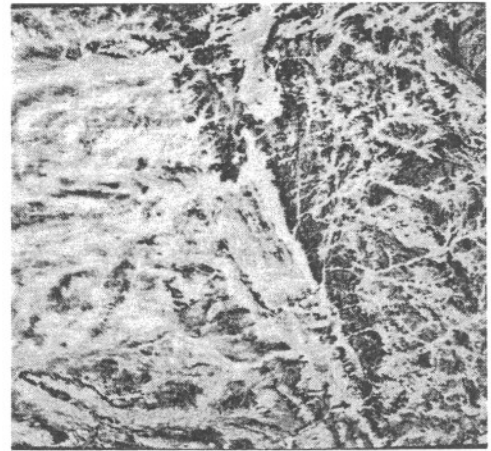


Fig.17 Contrast stretched image of Fig.16.

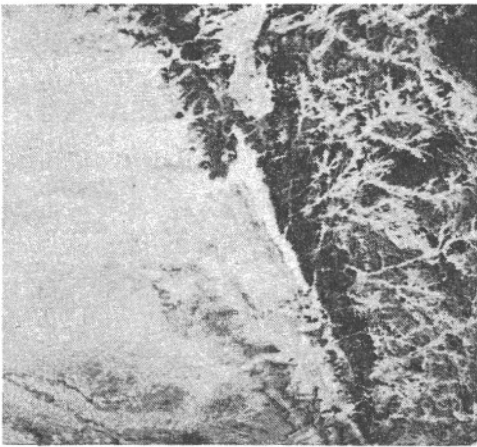


Fig.16 LANDSAT original image of a desert area in Africa (Band 7).

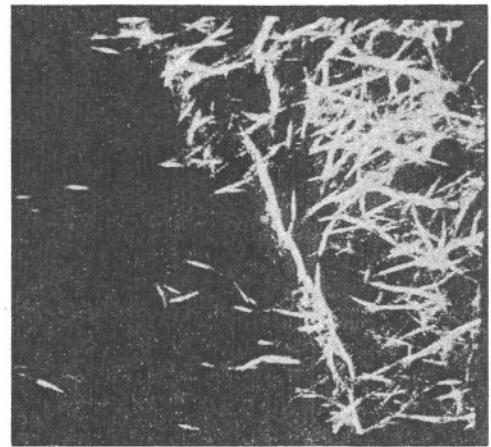


Fig.18 Lineament enhanced image of Fig.16 (STEP 1 same as Fig.4; STEP 2 same as Fig.6).

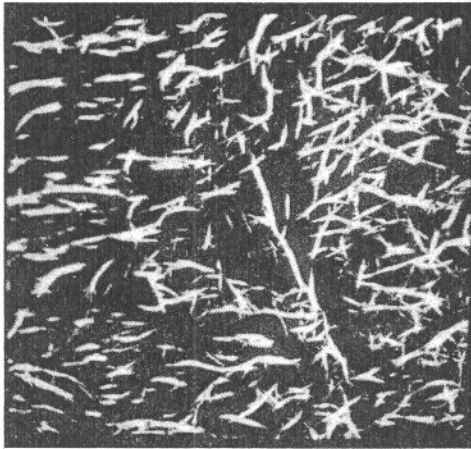


Fig.19 Lineament enhanced image of Fig.17
(STEP 1, STEP 2 same as Fig.18).

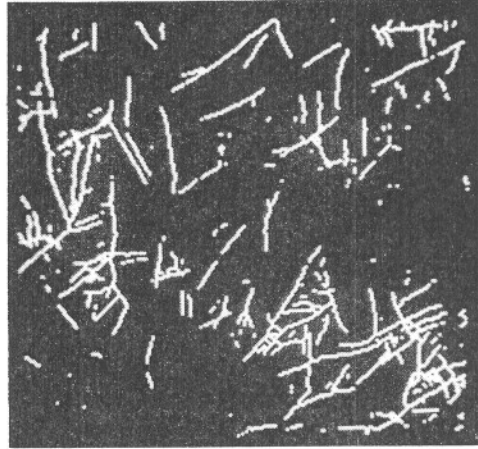


Fig.21 Thinned image of Fig.20.



Fig.20 Binarized image of Fig.11.

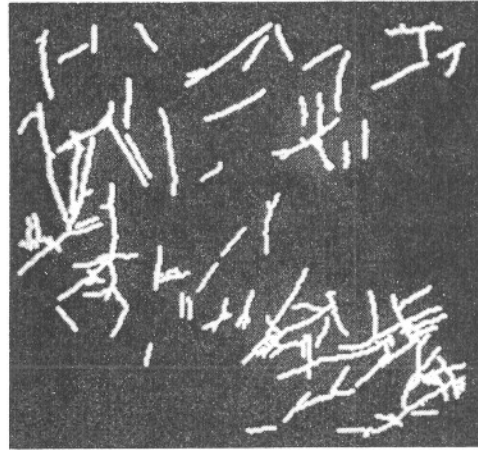


Fig.22 Line tracked image of Fig.21.

Dr. Hiroyasu Takahashi received the degrees of Bachelor, Master, and Doctor from the University of Tokyo in 1969, 1971, 1974 respectively. He joined IBM Japan as a systems engineer at DP division in 1974 and moved to Tokyo Scientific Center as a researcher in 1978. He was involved in multi-objective optimal planning in 1978 and has been involved in image processing since 1979. His research interests are in character recognition, statistical genetics, and programming of GO-game.