GEOLOGICAL LINEAMENTS ANALYSIS BY IFSAR IMAGES

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ABSTRACT:

Modern SAR interferometry (IFSAR) sensors delivering intensity images and corresponding digital terrain model (DTM) allow for a thorough surface lineament interpretation with the all-weather day-night applicability. In this paper, an automatic linear-feature detection algorithm for high-resolution SAR images acquired in Taiwan is proposed. Methodologies to extract linear features consist of several stages. First, the image denoising techniques are used to remove the speckle noise on the raw image. In this stage, the Lee filter has been chosen because of its superior performance. After denoising, the Coefficient of Variation Detector is performed on the result images for edge enhancements and detection. Dilation and erosion techniques are used to reconnect the fragmented lines. The Hough transform, which is a special case of a more general transform known as Radon transform, is a suitable method for line detection in our analysis. Finally, linear features are extracted from the binary edge image. The last stage contains many substeps such as edge thinning and curve pruning.

KEY WORDS: IFSAR, Coefficient of Variation Detector, Hough transform, Dilation and erosion

1. INTRODUCTION

The lineament extraction and analysis have been very important for the application of remote sensing to geology, particularly over large areas, since the lineaments often reflect the geological structures such as faults or fractures. Previous studies commonly use the Landsat Thematic Mapper data for extraction of lineaments. There has been less research carried out from Synthetic Aperture Radar (SAR) data because of the difficulty to "read" radar images. They differ from the natural human visual impression and the familiar analogy communicated by optical imagery. However, modern high-resolution SAR interferometry (IFSAR) sensors delivering intensity images and corresponding digital terrain model (DTM) allow for a thorough surface lineament interpretation with the all-weather day-night applicability. However, in geography investigation the intrinsic noise, speckle, becomes a critical factor for the lineament extraction from the high resolution SAR image, especially when building a modern computer aid detection system with automatic lineament detection capability [1].

The traditional lineament extraction scheme usually consists of the speckle reduction, target detection, and line extraction techniques. The analysis results often fail to clearly distinguish the main structures of the lineaments from the other chaotic features since there are a lot of interferences such as speckle and/or the effects from the randomly tilted surfaces. Besides, in terms of a whole view on geological settings, it has to not only determine large-scaled structure about mountain chain striking from image, but also resolve middle-to-small-scaled relieves that are consisted by locally crustal deformation. Such discrimination will enhance the comprehension about neotectonic development. In this paper, we develop a multi-scaled lineament analyse system by introducing the mathematical morphology into our detection processing in order to extract topographic lineament in varied scales.

Lee filter is used at first stage to remove the speckle noise on the raw image, following by increasing the image contrast by histogram equalization. In order to simultaneously speed up the processing time and erase the confusing small-scaled structure, the size of the raw SAR data is reduced to obtain the lower resolution image.

After the pre-processing, Coefficient of Variation detector is used to detect the edge features in the SAR image. The fragmented lines in the resulting edge map can be reconnected by mathematical morphology method, including dilation and erosion. In addition, between dilation and erosion stages, we add an erasing step which is intended to remove the small-scaled structures in the image that may cause confusion in the following line extraction stage.

Hough transform and back-projection are the main techniques for the line extraction in our approach. After the processing of the IFSAR images, some lineaments will be grouped into the known fault zones. Others should be validated by more field results and analyses.

2. METHODOLOGY

The procedure of the proposed lineament analysis system is shown in figure 1. Since the main structures of the ridges and faults are often confused with speckle and the other small-scaled structures in a SAR image, multi-resolution analysis has been used in the beginning of the image processing to enhance the nature lineament features and smooth the detail structures.

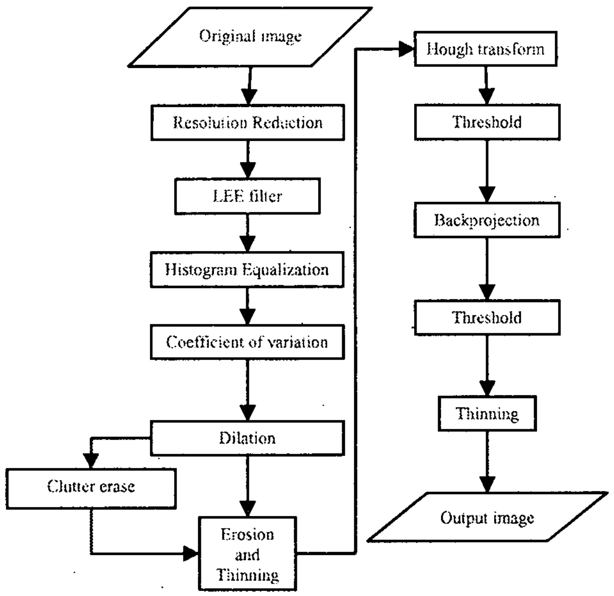


Fig. 1. Block diagram of the lineament analysis system

Wavelet transform is one of the multi-resolution analysis techniques that could achieve the goal of resolution reduction [2]. Haar, Daubechies and morlet scaling functions are tested in our simulation. With pyramidal image structure, the low pass filtered image (LL) with lower resolution can be obtained. In out simulation, the raw image of 1024X1024 pixels is downsampled to a 128X128 pixels sample image which is used in the lineament analysis processing.

2.1 Image Denoising

Lee filter has a superior performance in reducing speckle noise, by generating statistics in a local neighborhood and comparing them to the expected values. The equation of Lee filter [3] is

$$s' = \bar{s} + g(x - \bar{s}) \tag{1}$$

$$\text{var}(s) = \frac{\text{var}(x) + \bar{s}^2}{\sigma^2 + 1} \tag{2}$$

$$g = \frac{\text{var}(s)}{\text{var}(s) + \sigma^2 \bar{s}^2} \tag{3}$$

Where $\bar{s}$ = local mean of moving window
x = current pixel value
var(x) = the variance of pixels in the moving window
σ = the variance of speckle

The parameter σ is well described by a multiplicative noise model. For example, for a 1-look amplitude image SAR images, variance σ =0.52, and for a 4-look amplitude image, σ =0.25.The filter can be considered as an adaptive-mean filter [4]. This developed to smooth speckle without demoting the sharpness of the image.

2.2 The Coefficient of Variation Detector

In general, edge detector is too sensitive to detect large-scaled structure, and they are especially noteworthy in the case of high-resolution SAR image. Avoiding linear feature and noise be confused by general edge detections, Coefficient of Variation detector [5] [6] is more effective to extract linear feature. Two statistical parameters required in the detector are

$$M = \frac{1}{N}\sum_{i=1}^{N} s_i \tag{4}$$

$$S = \sqrt{\sum_{i=1}^{N}(s_i - M)^2 / N - 1} \tag{5}$$

where s_i = current pixel value of local moving window
N = the pixel number of local moving window

Based on *S/M*, and two threshold values related to the look number *L*, $1/\sqrt{L}$ and $1/\sqrt{1+2L}$ in the flat or nonhomogeneous areas, the decision principle is as follows:

A. Assigned to edges when *S/M* ≧ $1/\sqrt{1+2L}$

B. Assigned to homogeneous class if *S/M* ≦ $1/\sqrt{L}$

In our study, Coefficient of Variation detector provides a good performance in lineaments detection for the SAR image.

2.3 Mathematical Morphology

Edge map is obtained after the image processing by the Coefficient of Variation Detector. This bi-level image comprises of fractured linear features and lots of surviving residues of the small-scaled structures. Therefore, the image processing techniques developed in the mathematical morphology are introduced into our algorithm in order to reconnect the fragmented lines in the resulting edge map. They consist of dilation, erosion and thinning.

In mathematical morphology [7], dilation method could be used to fill holes and broken areas, and connect areas that are separated by spaces smaller than the size of the structuring element. However, the dilation process also expands smaller clusters that are useless and unfavourable for line extraction. What we are interested is the lineaments rather than the small clusters that are often referred to as the "clutter". Therefore, we proposed a clutter erasing step after the dilation processing. The principle is labelling every separated cluster and calculating the mass center and the standard deviation of the pixel distribution in every cluster. Bar-shape clusters which are most likely to be line structures usually have quite large standard deviation and should be left for next processing. Clutter always has smaller standard deviation and can be removed by setting a threshold (see Fig. 3.). In addition, the two-dimensional standard deviation can also provide the direction information of each cluster, which helps the directional statistics in geophysical lineament analysis. The proposed method is suitable for multi resolution SAR images and it did improve the performance of the following linear feature extraction.

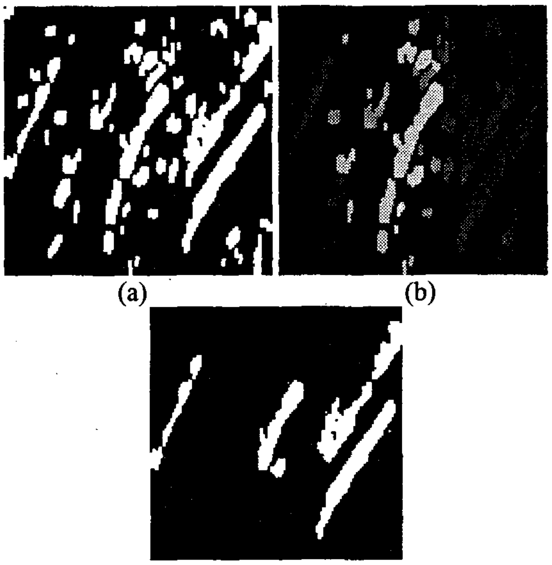


Fig. 2. Clutter removing process (a) Dilation of the bi-level image after edge detection. (b) Labelling clusters with colours disposing. (c) Erasing the clusters having the smaller standard deviation of the pixel distribution.

Contrary to dilation, erosion shrinks the remainder of the clusters to the original size. After erosion and before line extraction, the thinning process should be performed in order to obtain a skeleton of the binary edge map where the set of skeletal pixels can be considered as the medial axis of the cluster.

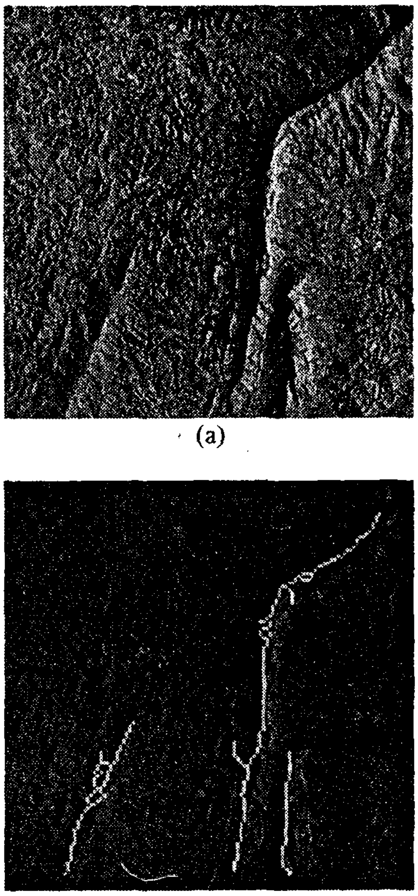
2.4 Hough Transform and Back projection

Over the past few years a considerable number of studies have been made on straight lines detection. The Hough transform is a popular and powerful method for detecting parametrically described shapes such as lines in images. Since the detected lines often overlap seriously in the spatial domain, the threshold in the transformed domain (ρ, θ) should be set appropriately.

3. RESULTS

In the research, 10m-resolution SAR images acquired in 2004 at the south-western part of the Taiwan are used to test the proposed scheme shown in Fig.1. Two mountain areas were selected as the test site. The raw images are downsampled from 1024 X 1024 to 128 X 128 pixels by multi-resolution analysis.

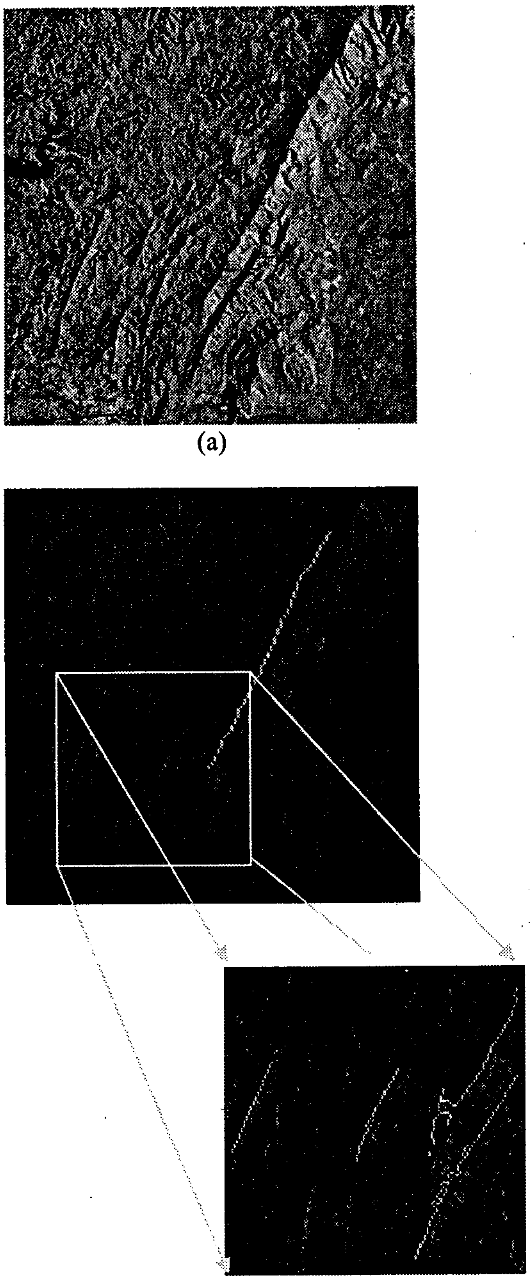
Fig. 3 (a) shows the original IFSAR image gathered at the Nei-men-shiang, Gau-shiung-shian. Fig. 3 (b) represents the lineament extraction results by the proposed algorithm. It is clear that the extracted lineaments correspond to the large-scaled topography structures which are the main mountain ridges in the image. Another case is shown in Fig. 4 (a) where the linear features in the SAR image of the Tachienshan - Chukou fault in the southern Taiwan are obvious. However, there are middle-scaled lineaments beside the the Tachienshan - Chukou fault. With the proper setting of the threshold during the mathematical morphology processing, the large-scaled lineaments are shown in Fig. 4 (b). Nevertheless, by adjusting the threshold parameter, the middle-scaled lineaments can also be extracted.



(a)

(b)

Fig. 3. Lineaments extraction from the IFSAR image gathered at the Nei-men-shiang, Gau-shiung-shian.



(a)

(b)

Fig. 4. Lineaments extraction from the IFSAR images of the Tachienshan - Chukou fault in the southern Taiwan.

4. CONCULSION

IFSAR image can reveal many sorts of geological structures, for e.g., fault and fold, which can greatly benefit the discernment of neotectonic elements. In terms of a whole view on geological settings, it has to not only determine large-scaled structure about mountain chain striking from image, but also resolve middle-scaled relieves that are consisted by locally crustal deformation. Such discrimination will enhance the comprehension about neotectonic development. In this paper, we take advantage of the airborne IFSAR images gathered at southwest Taiwan to extract geological lineaments in varied scales.

As extracting the distinct lineament corresponding to mountain ridge via IFSAR analysis, the small-scaled features, e.g. fold, play a role as clutter noises in treatment. The approach for gathering major mountain lineament is to perform the mathematical morphology technology and calculating the standard deviation of the pixel distribution for each cluster in the dilated edge map. Clutter which always has the smaller standard deviation can be removed by setting a proper threshold. Nevertheless, the middle-scaled lineaments can still be remained and become the considerable features for local structure survey. We can accommodate the tunable threshold value to project out these lineaments. The mathematical morphology technique is implemented for enhancement of the goal features in different scales. This technique can also make lineament discrimination combined with multi resolution analysis.

The clustered lineaments will further be used to a series of statistic analyses tied with deformation model to characterize local stress property. Our study can therefore provide useful information about neotectonic stress/strain at southwest Taiwan, by means of IFSAR analysis.

5. REFERENCE

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