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Full Length Research Paper

Developing adaptive algorithm for automatic detection of geological linear features using RADARSAT-1 SAR data

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Synthetic aperture radar (SAR) has been recognized as a powerful tool for geological features detection. This work introduces a new approach for modification of adaptive Lee algorithm to semi-automatically detected geological features from RADARSAT-1 SAR data. This is based on modification of Lee algorithm formula by using 2D Gaussian convolution formula. The result shows that the new formula of Lee algorithm can be delineated lineament features in RADARSAT-1 SAR data. The new formula based on 2D Gaussian performed better in semi-automatically detected lineament features as compared with Lee algorithm. The modification of Lee algorithm has a small standard deviation of 3.54 as compared to Lee algorithm.

Key words: Adaptive algorithm, Lee algorithm, 2D Gaussian algorithm, linear feature, SAR Satellite Data, RADARSAT-1 SAR.

INTRODUCTION

Speckle is basically a form of noise, which degrades the quality of an image and may make its visual or digital interpretation more complex (Hondt et al., 2006). A speckle pattern, consequently, is a random intensity pattern fashioned by the mutual interference of a set of wavefronts having different phases. Under this circumstance, they are added together to give a resultant wave whose amplitude and intensity vary randomly. In this context, Lopes et al. (1993) stated that if each wave is modelled by a vector, then it can be seen that a number of vectors with random angles are added together. The length of the resulting vector, therefore, can be anything from zero to the sum of the individual vector lengths-a 2-dimensional random walk, sometimes known as a drunkard's walk. Further, when a surface is illuminated by a microwave, spectra according to diffraction theory, each point on an illuminated surface acts as a source of secondary spherical waves. The microwave spectrum at any point in the scattered microwave field is made up of waves which have been scattered from each point on the illuminated surface. If the surface is rough enough to create path-length differences exceeding one wavelength, giving rise to phase changes greater than 2π, the amplitude and the intensity of the resultant backscatter microwave vary randomly.

In general, all radar images appear with some degree of what we call radar speckle. Speckle appears as a grainy "salt and pepper" texture in an image (Lopes et al., 1990; Lopes et al., 1993; Berens, 2006). This is produced by random constructive and destructive interference from the multiple scattering returns that occur within each resolution cell (Touzi, 2002; Yu and Scott, 2002; Hondt et al., 2006; Helmy and El-Taweel, 2010). As an example, a homogeneous target, such as a large grass-covered field, without the effects of speckle would generally result in light-toned pixel values on an image. However, reflections from the individual blades of grass within each resolution cell result in some image pixels being brighter and some being darker than the average tone, such that the field appears speckled. The high speckle noise in

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SAR images, however, has posed great difficulties in inverting SAR images for mapping morphological features. Speckle is a result of coherent interference effects among scatterers that are randomly distributed within each resolution cell (Ballard and Brown, 1982).

The speckle size is a function of the spatial resolution, which induces errors in the morphological feature signature detections. In order to reduce these speckle effects, appropriate filters, e.g., Lee, Gaussian, etc. (Lee et al., 2002), can be used in the pre-processing stage. The effectiveness of these speckle-reducing filters, however, is influenced by local factors and application. In fact, all speckles in SAR images are related to local changes in the earth surface roughness. In this context, Yu and Scott (2002) and Hondt et al. (2006) stated several limitations of the speckle filtering approach.

They reported that the size and shape of the filter window can affect the accuracy level of despeckle filters (Maged, 2001a). For instance, a large window size should form a blurred output image, while a small window will decrease the smoothing capability of the filter and leave speckle. In spite of despeckle filters performing edge enhancement, speckle in the neighbourhood of an edge (or near a point feature with high contrast) will remain after filtering (Nezry et al., 1993; Yu and Scott, 2002). Furthermore, the thresholds used in the enhanced filters, although motivated by statistical arguments, are ad hoc improvements that only demonstrate the insufficiency of the window-based approaches. Further, Ballard and Brown (1982) have implemented 3 x 3 pixels median filtering operation to despeckle SAR data in order to extract morphological features. A new approach has been introduced by Wong et al. (1999) to reduce the speckle microtexture by using the wavelet domain algorithm. In addition, Maged (2001b) has implemented Lee algorithm with different texture algorithms to determine feature linearity in SAR images. According to Maged (2001a), the Lee algorithm avoids a decreasing resolution by making a weighted combination of running average with neighbour pixels. This reduces the noise in the edge areas of the objects without sacrificing edge sharpness (Nezry et al., 1993).

Recently, Maged and Genderen (2001) have utilized Canny algorithm to automatically detected linear geological features from multi SAR data sets. Further, Maged (2002) has concluded that the Canny algorithm is proper algorithm to delineate the linear and concave features from multi SAR data. In addition, he has implemented Lee algorithm with different texture algorithms to determine feature linearity in SAR images. According to Maged (2001a), the Lee algorithm avoids a decreasing resolution by making a weighted combination of running average with neighbour pixels. This reduces the noise in the edge areas of the objects without sacrificing edge sharpness (Maged and Genderen, 2001). This work has hypothesized that linear features such as morphological features- faults and lineaments; urban; infrastructures and their surrounding backscattered environmental signals in the SAR data can be modelled as adaptive filter. In this context, a new formula of adaptive algorithm can be used as a semiautomatic tool to extract morphological features from SAR data.

RESEARCH METHODS

Modification of adaptive algorithm

Due to random fluctuations in the signal observed from a spatially extensive target represented by pixel, speckle noise is generally present in radar image. According to Touzi (2002), there are two approaches to the suppression of radar image speckle: (i) multi-look processing and (ii) filtering techniques. The disadvantage of multi-look processing is the degradation in image resolution (Touzi, 2002). The filtering methods are used to smooth the speckle noise with persevering image resolution (Lopes et al., 1990). In this context, adaptive filters are more likely to preserve details such as edges or high textures areas. In fact, the degree of smoothing is function of local radar image statistics (Lopes et al., 1993). According to Maged (2001a), a number of adaptive speckle filters have been proposed, the best known being the Lee algorithm (Lee et al., 2002). In fact, Lee algorithm is proper algorithm for linear feature detection due to its advantages for smoothing out noise and retaining edges or shape in the SAR images (Maged, 2002). Three assumptions are taken into account: (i) SAR speckle is modelled as a multiplicative noise, that is, the visual impact of multiplicative noise is that the noise level is proportional to the image grey level; (ii) the noise and signal are statistically independent; and (iii) the noise and signal variance of a pixel is equal to its local mean and local variance estimated within a window centered on the pixel of interest.

The first assumption implies that where zij is the noise affected image pixel x at location (i, j), zij is the signal that one wishes to recover and vij is multiplicative noise

$$zij = xijvij \tag{1}$$

In order to simplify the expression, the subscripts are omitted in the following discussion. Normally, the mean μv of noise v takes value of unity (Lee et al., 2002) and the noise standard deviation σv can be obtained from a local window located over a homogeneous area of the image such as at water surface. The idea of extracting σv in this way based on the second assumption, that the parameters x and v in Equation (1) are independent. Following Lee et al. (2002) mean of a noise fading signal μz can be expressed by:

$$\mu x = \mu x \, \mu v \tag{2}$$

Where μx and μv are the means of x and v, respectively. Using equation 1 into equation 2 the variance $\sigma^2 z$ of z can be expressed as:

$$\sigma^2 z = E\,(xv - \mu x\,\mu v)^2$$
$$= E(x^2)\,E\,(v^2) - \mu^2\,x\,\mu^2 v \tag{3}$$

Where E denotes the expected value. Suppose that the window is placed over a homogenous area, then one can set $E(x2) \sim \mu 2x$ because over the area the pixel values should be closed to each other. Equation 3 can be further derived as:

$$\sigma^2 z = \mu^2\,x\,\sigma^2 v \rightarrow \sigma v = \sigma z \mu^{-\square} x \tag{4}$$

Therefore, Lee algorithm is implemented to SAR data by sliding rectangular window width and odd length. The windows size is selected in the two dimensions over the input images. At each window position, the mean and variance of the images intensity are estimated. Let $a \in L^x$ for some 2-dimensional point set z be the SAR source image which has unbounded extent. Then, Gaussian smoothing (b) of an image (*z*) is achieved by convolving it with the Gaussian G:

$$b(i,j)=a(i,j)*G(i,j)=a(i,j)*G(i)*G(j) \quad (5)$$

Where $G(i,j)$ is Gaussian filter that provides localization best in both the spatial and frequency domains. Then, the Gaussian smoothing b of SAR image z would be given by

$$b = a \oplus s \quad (6)$$

Where S is defined by

$$s = \frac{1}{2\pi\sigma_Z^{\,2}} e^{\frac{-(i-v)^2-(j-w)^2}{2\sigma_z^2}} \quad (7)$$

Where σ_Z is variance of Gaussian smoothing SAR image, *z*, *v* and *w* are pixel locations for Gaussian smoothing b of SAR image z. In practice the bounded Lee image must be smoothened with a bounded template. In such cases, truncating the extent template will lead to introduction of bias by smoothing even at those points where the template support is entirely contained within the Lee image point set. This is due to the integral of the truncated Gaussian being less than one. To achieve an unbiased result, the template must be constructed as follows:

$$s_{(i,j)}(v,w) = \frac{1}{2T\pi\sigma_Z^{\,2}} e^{\frac{-(i-v)^2-(j-w)^2}{2\sigma_z^2}} \quad (8)$$

Using equation 8 into equation 4 one can obtain a new formula

$$\begin{aligned} Z &= a \oplus s \oplus \hat{X} \\ &= b \oplus \hat{X} \end{aligned} \quad (9)$$

The purpose of equation 9 is to extract one high-intensity line or curve of fixed length and locally low-curve from SAR image.

Steps for adaptive algorithm modification are:

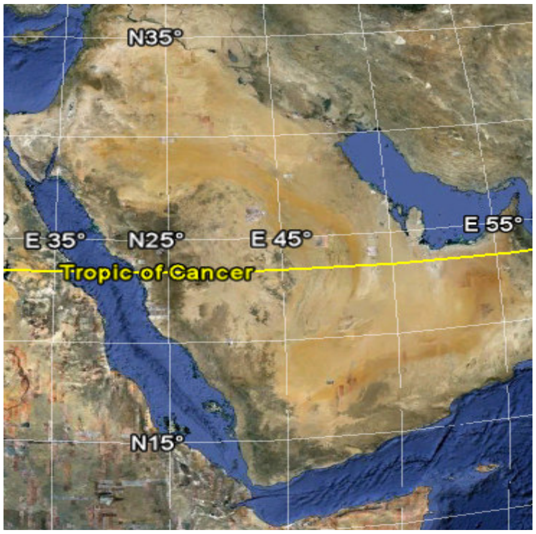
- Choose the window size.
- Determine the speckle noise *µx, µv,* □ *σv.*
- Apply Lee algorithm to selected amplitude image.
- Then smooth Lee image using *zij = xijvij.*
- Do for each pixel I on smooth Image *I*.
- Center the window on the pixel *I*.
- Generate noise smooth image by convolution output.
- Result automatic linear features.
- End Do.
- End.

RESULTS AND DISCUSSION

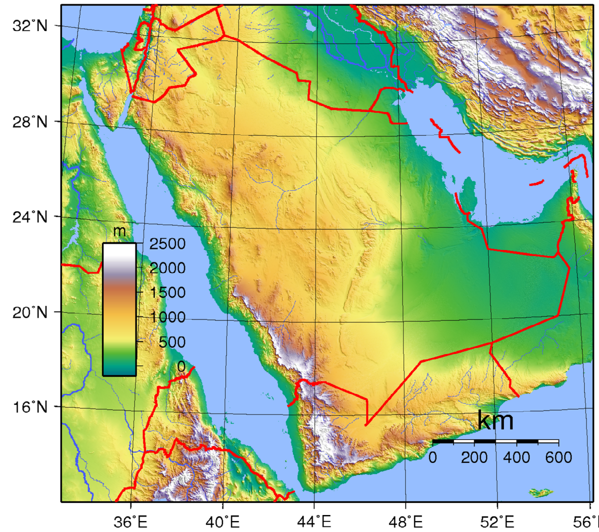
Figure 1 shows the geographical location and geological elevation model of selected test area. Figure 1a shows the geographical location of selected test area which is part of Arabian shield. Therefore, Figure 1b shows the digital elevation variation of Arabian shield with 2000 m height. In addition, the Arabian-Nubian Shield (ANS) is an exposure of Precambrian crystalline rocks on the flanks of the Red Sea. The crystalline rocks are mostly Neoproterozoic in age. Geographically - and from north to south - the ANS includes the nations of Israel, Jordan, Egypt, Saudi Arabia, Sudan, Eritrea, Ethiopia, Yemen, and Somalia. The ANS in the north is exposed as part of the Sahara Desert and Arabian Desert, and in the south as the Ethiopian Highlands, Asir Province of Arabia and Yemen Highlands (Wikipedia, 2010).

Figure 2 shows the RADARSAT-1 SAR S2 mode amplitude data which covered an area located between 38° 50' E to 39° 40' E and 21° 50' N to 22° 20' N along the western coast of the Kingdom of Saudi Arabia (Figure 1). The RADARSAT-1 SAR is distinctive in that it has a characteristic speckled effect which looks like 'salt and pepper' noise (Figure 2). The resulting grainy appearance can be seen in Figure 1. This speckle noise is caused by random interferences when the signals arrived on the roughness of the studied areas and objects, resulting in high spatial-frequency wave front deformations (Lopes et al., 1990). The speckle pattern super-imposed on the images makes it very difficult for it to be used in many applications (Lopes et al., 1993; Maged 2001a; Touzi 2002). Therefore, the morphological features such as morpholineaments existed in RADARSAT-1 SAR data which cannot be extracted and interpreted due to the speckle impacts (Figure 2). Figure 3 shows the result of Lee algorithm with kernel window size of 7 x 7. It is obvious the clear appearance of the lineament features in RADARSAT-1 SAR S2 beam mode. In fact, the Lee algorithm avoids a decreasing resolution by making a weighted combination that runs averagely with the neighbour surrounding the pixels. This reduced the noise in the features' edge areas without sacrificing edge sharpness.

Figure 4a shows the Lee output result while Figure 4b shows the output results of new algorithm. The linear features in Figure 4a are clearly visualized in SAR data; however, linear features can be discriminated easily in Figure 4b. It is interesting to find that the modification of Lee algorithm by using a convolution 2-D Gaussian formula produced a semi-automatically detect lineament features from SAR image (Figure 4). This indicates that the implementation of new formula is able to separate the lineament features from the surrounding pixels on background in SAR image. This can be confirmed by the lower error standard deviation value of new formula that is, 3.54 as compared to Lee algorithm (Figure 5). Figure 6 shows the ability of new formula for automatic detection



a



b

Figure 1. Peninsular Arabia (a) topographic image obtained from Google earth and (b) Digital elevation map.

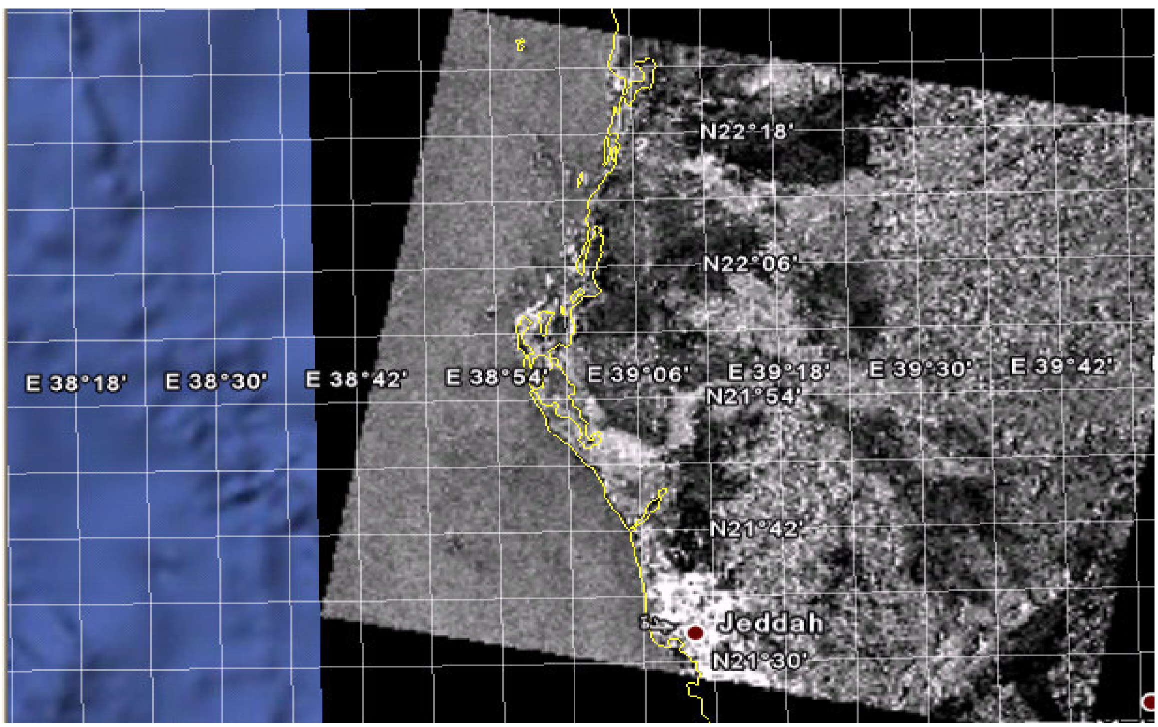
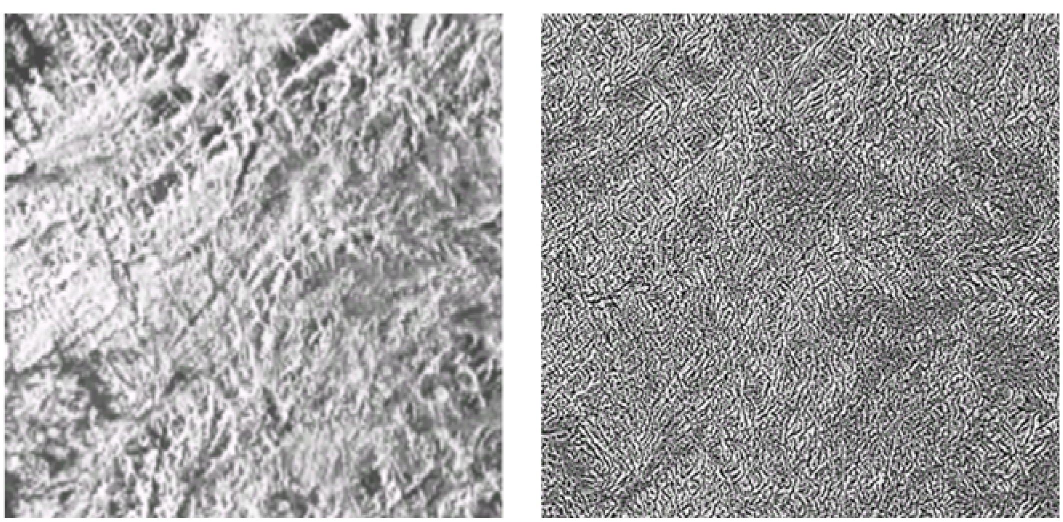


Figure 2. RADARSAT-1 SAR raw data.

of other linear features such as urban area in SAR data. In addition, the linear feature of infrastructure such as road and bridges are clearly observed. This result confirms the study of Maged (2002). According to Lopes et al. (1990), the integral of the truncated 2-D Gaussian convolution being less than 1 produces bias by smoothing even at those points where the template support is entirely contained within the Lee image point set. Further, the sharp appearances of lineaments are achieved by convolving result of Lee algorithm with the Gaussian. It might be 2-D Gaussian convolution able to delineate the linear and concave features by reducing

Figure 3. RADARSAT-1 SAR data after using Lee algorithm.



a b

Figure 4. Visual comparison between (a) Lee algorithm and (b) Lee modification formula results.

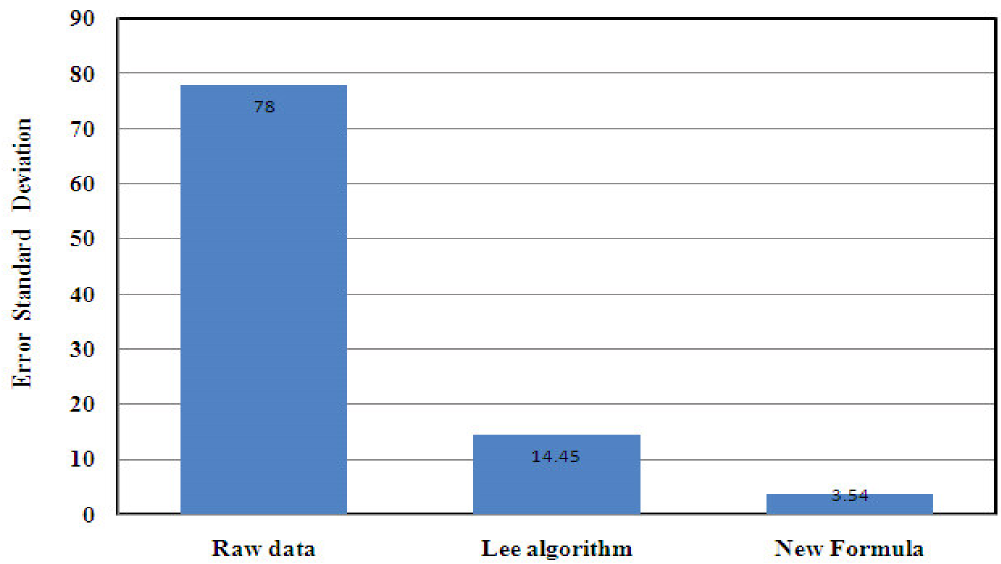


Figure 5. Statistical standard deviation of Lee and modification of Lee algorithms.

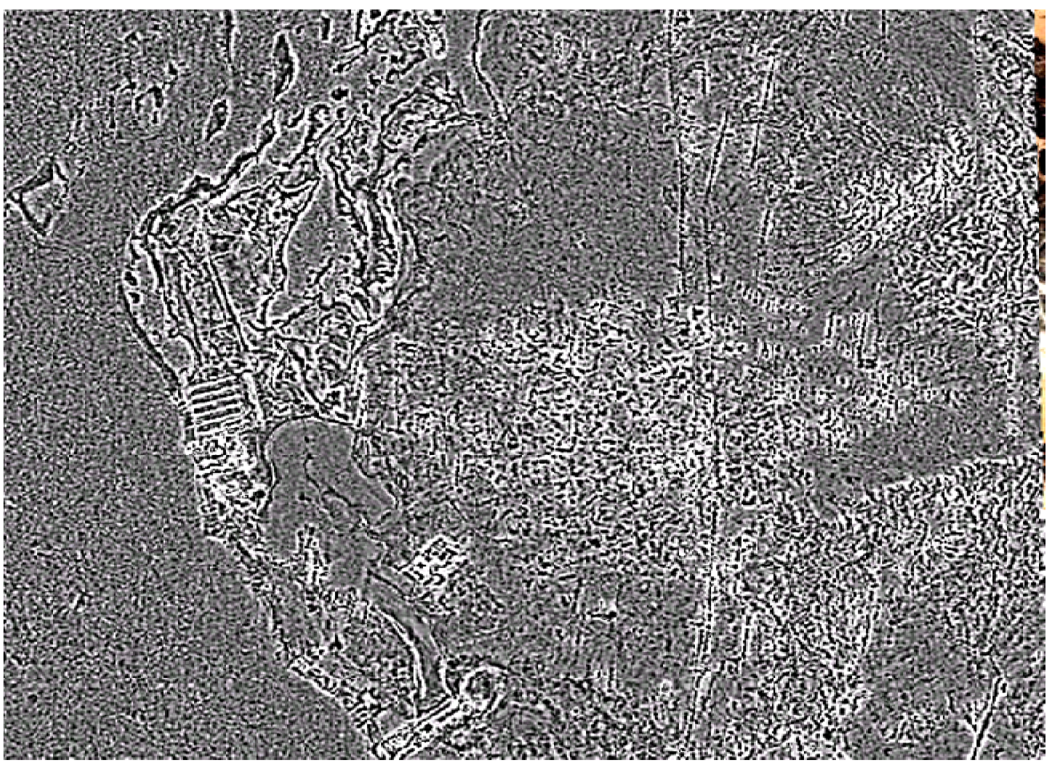


Figure 6. Automatic detection of urban area and infrastructure using modification of Lee algorithm.

speckles intensity in SAR image. Therefore, the new formula has a similar result as wavelet and Canny algorithm (Maged 2002; Wong et al., 1999; Xie et al., 2002; Vasile et al., 2006). In general, new algorithm provides the optimal line or curve length n that satisfies the figure-of-merit (FOM) function that embodies a nation of best curvature (Figures 4 and 5). This technique is useful in the case of high intensity line or curve of fixed length and locally low curvature boundary is known to exist between edge elements and high noise levels in the SAR data. It could be used for filling in gaps left between an edge detecting-thresholding-thinning operations (Figure 5). Finally, multistage optimization procedures have performed better use of new formula due to their abilities to search the actual edge pixels lie on the boundary of lineament features being segmented. This can explain that the evolution of new formula is accomplished by using the multistage process, which is robust and accurate, and that all edge points fall on the boundary of lineament features in SAR image.

Conclusion

This work has derived a new formula that is based on the combination of Lee and Gaussian algorithms, which is used to extract linear features from RADARSAT-1 SAR S2 mode data. In doing so, three assumptions are considered (i) SAR speckle is modelled as a multiplicative noise that is, the visual impact of the multiplicative noise is that the noise level is proportional to the image grey level; (ii) the noise and signal are statistically independent; and (iii) the noise and signal variance of a pixel is equal to its local mean and local variance estimated within a window centered on the pixel of interest. The result shows a clear appearance of morpholineament, urban, and infrastructure features due to speckle reduction. This confirms a low error standard deviation value of 3.54 as compared to Lee algorithm. In conclusion, the modified formula of Lee algorithm has improved distinction of morpholineaments, urban features, infrastructure features such as roads and bridges from the surrounding environment features. This new approach can be used as an automatic tool to extract linear features from SAR data.

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