Abstract - Multiplicative noise makes the interpretation of image extremely difficult, and the fixed-size window filters cannot achieve good trade-off between noise suppression and edge keeping. Based on adaptive windowing and local structure detection, a new filtering algorithm of multiplicative noise is developed in this paper. The sliding window size is automatically adjusted by adaptive windowing, and the local structure detection is required for each window determined because appearance of point target and edge feature cannot satisfy the basic premise of stationary in increment for all statistical filters. Point target is preserved to keep edges and fine details, and the most homogeneous semi-window on which the central pixel lies is chosen by gradient masks to enhance noise reduction in edge areas. The denoising experiments demonstrate that the proposed filter is superior both in noise suppression and in fine detail preserving.

Keywords: Multiplicative noise, stationary in increment, adaptive windowing, structure detection.

1 Introduction

Multiplicative noise usually appears in synthetic aperture radar (SAR) images, and it degrades the quality of images significantly [1,2,3]. Traditional mean filter and median filter appeared earlier in the history of image processing. The mean filter averages neighboring pixels in current window, and it can effectively reduce noise at a cost of edge and fine details. The median filter can preserve the edge well but it cannot smooth noise as much as the mean filter does. Their filtering performance are degraded seriously especially for the multiplicative noise. The most well-known and widely used filter for multiplicative noise is the adaptive filter proposed by Lee, which uses local mean and variance of the fixed-size window to determine the degree of smoothing [4]. It is said that the Lee filter is a better trade-off between noise reduction and fine detail preserving than mean and median filter, but choosing the window size correctly is still a problem not answered. Generally speaking, a larger window may lead to a loss of fine details in the image, but a smaller window usually means insufficient noise reduction in homogeneous area. To solve this problem, the adaptive windowing was suggested [5]. This algorithm automatically adjusts the window size by regional characteristics. In homogenous area a larger window is used to suppress noise completely while in heterogeneous area a smaller one is chosen to preserve edge and fine details.

It can be noted that all statistic filters are supposed on the premise of stationary in increment [6]. Only under this condition Lee filter is available because the sample mean and variance of a pixel is equal to its local mean and variance based on pixels within a neighborhood surrounding it. However, the appearance of point target and edge feature in moving window makes this assumption invalidated. So it is desirable to use structure detection to make sure of no existence of point target and edge feature in current window even the latter is obtained by the adaptive windowing. Point targets should be preserved according to Lopes’ view of statistics classification [7], and the orientation of edge should be located by local gradient information [8]. The filtering is accomplished by calculating local statistics in the most homogeneous semi-window on which the central pixel lies. Consequently, noise reduction in edge area is enhanced.

This paper is organized as follows. In section 2, the multiplicative noise model is introduced as well as its important characteristic. In section 3, the adaptive windowing is presented using the coefficient of variation as the homogenous test. In section 4, point target and edge feature are detected by the local structure detection, and the maximum homogeneous semi-window is determined for the calculation of local statistics. In order to evaluate the performance of the proposed filtering algorithm based on adaptive windowing and local structure detection, some denoising experiments on simulated and real SAR image are given in section 5. Finally, this paper is concluded with a short summary in section 6.

2 Multiplicative noise model

For an image corrupted by multiplicative noise the observed pixel value at \((i,j)\) is represented by

\[
y(i, j) = x(i, j) \cdot n(i, j),
\]
where  $x(i, j)$ is the pixel value of original image and $n(i, j)$ is the multiplicative noise with unitary mean and $\sigma_n^2$ variance. Here the original image and the noise are assumed to be independent with each other for simplification.

There is an interesting and important characteristic for the multiplicative noise model. In the noisy image, the observed local standard deviation is proportional to the observed local mean in the image area with constant reflectivity, and their ratio is equal to the standard deviation of noise [9]. However, the ratio is greater than the noise standard deviation in the area without constant intensity. The more the intensity changes, the larger the ratio is. So this ratio called coefficient of variation is usually used as a homogenous test in noisy image. If the coefficient of variation in current window is less or equal to the noise standard deviation, it means the appearance of homogenous area, or else the heterogeneous.

### 3 Adaptive windowing

The adaptive windowing was proposed to overcome the limitation of conventional filters with fixed-size window. Denoting $L$ as the window size, the $L\times L$ window for the current pixel at $(i, j)$ is denoted by $W$. As shown in section 2, the coefficient of variation can be used as a homogenous test in noisy image. Firstly, the sample mean is given by

$$\mu = \frac{1}{L^2} \sum_{k,l \in W} y(k,l),$$  \hspace{1cm} (2)

and the sample variance is

$$\sigma^2 = \frac{1}{L^2} \sum_{k,l \in W} (y(k,l) - \mu)^2.$$ \hspace{1cm} (3)

Then the coefficient of variation at current pixel $(i, j)$ is defined by

$$C = \frac{\sigma}{\mu}.$$ \hspace{1cm} (4)

The size of next window is determined by comparing the $C$ with the threshold $T$. If $C$ is greater than $T$, the window size is decreasing continuously until its minimum, or else increasing until its maximum predefined. The threshold $T$ is suggested in [5]. In order to save the computational loads, the boundary pixels of current window are only used for the decision of next window size. Then, the threshold must be changed as follows [5]

$$T = \eta \left[ 1 + \frac{1+2\sigma_n^2}{8(L-1)} \right] \sigma_n, \hspace{1cm} (5)$$

where $\eta$ is a system parameter determining the degree of smoothing. Obviously, the threshold $T$ only relies on the window size if the noise variance and the system parameter are fixed. When the size of window is small, the threshold becomes higher and the window grows quickly to get higher calculating precision and stronger noise suppression. However, when the window size is largish, the threshold becomes lower and the window can hardly enlarge. This, obviously, is helpful for the preservation of edges and fine details. So this adaptive characteristic is shown on the relation of the threshold to the window size.

It can be noted that the changing direction of window should be limited for the adaptive windowing using boundary pixels of current window. Moving window should be enlarged gradually from the smallest to the biggest because this method choosing boundary pixels of current window as sample points is not sensitive to the inner structure of window.

### 4 Local structure detection

The appearance of point target and edge feature shown in Fig. 1 makes the basic premise of stationary in increment for all filters based on local statistics invalidated [6], so it is necessary to consider them respectively using structure detection [7,8,10]. For each pixel, if the coefficient of variation calculated in the smallest moving window is greater than the threshold suggested by Lopes, the central pixel is regarded as point target and its value should be preserved. If not, the adaptive windowing introduced above is started until an appropriate window size is obtained. If the window is too small, all samples in the current window are directly used to calculate the local statistics in order to keep the sample calculation robust. Once the window size is greater than a predefined one, edge feature is detected using different gradient masks in order to keep the premise of stationary in increment valid. These gradient masks are shown in Fig. 2. In order to enhance the noise reduction in edge area, the maximum homogeneous area on which the central pixel lies is chosen as the filtering semi-window. Possible semi-windows are shown in Fig. 3. For the edge features shown in Fig. 1(b) and Fig. 1(c), the semi-window determined finally is shown in Fig. 4. The flow chart of this algorithm for multiplicative noise based on adaptive windowing and local structure detection is shown in Fig. 5 for each pixel, where $T$ is the Lopes’ threshold used to detect the point target, $W$ is the final window size determined by the adaptive windowing, and $T_z$ is the predefined threshold determining whether the edge detection is used or not.
The proposed filtering algorithm introduced above is based on adaptive windowing and local structure detection. The adaptive windowing is used to keep the sample calculation robust, and the local structure detection is used to keep the premise of stationary in increment valid. These two conditions are necessary for the optimal filters [6]. However, they are usually in contradiction with each other and hardly satisfied at the same time. Generally speaking, robust condition is satisfied easily for large window, but much larger window usually leads to the dissatisfaction of the stationary condition. From the point of view of satisfaction of robust condition and stationary condition, the main idea of the proposed algorithm can be summarized in Fig. 6. First, point targets are detected and preserved, which can be regarded as a special structure detection not using the gradient masks but the Lopes’ view of statistical classification. Next, for the non-point target region, adaptive windowing is used to obtain an appropriate filtering area. Last, according to the structure detection based on the gradient masks, edge features are located to satisfy the stationary condition and then the maximum homogeneous semi-window is determined to satisfy the robust condition. In a word, what the proposed
Fig. 6 Main idea of the proposed algorithm based on adaptive windowing and structure detection

5 Simulation and results

A simulated image is generated using the multiplicative noise model described above with unitary mean and 0.05 variance. Fig. 7(a) is the original image and the quality of this image is seriously degraded by such noise. The mean and median filtered images are shown in Fig. 7(c) and Fig. 7(d), respectively. It can be seen that median filter cannot smooth noise effectively and mean filter blurs edge and fine details seriously. The Lee and proposed Lee filtered image based on adaptive windowing and local structure detection are shown in Fig. 7(e) and Fig. 7(f), respectively. Obviously, Lee filter is a better trade-off between noise suppression and edge preserving compared to the mean and median filter. However, there still exists some noise not filtered in homogeneous area for Lee filter with fixed window. Compared to the original Lee filter, the proposed one can achieve better noise reduction both in homogeneous area and in edge area, and the capability of fine detail preserving is more obvious. Same conclusion can be obtained from the denoising experiments on the real SAR image shown in Fig. 8.

Fig. 7 Result images for simulated image
(a) Original image (b) Noisy image by multiplicative noise with unitary mean and 0.05 variance (c) Mean filtered image with 3×3 window (d) Median filtered image with 3×3 window (e) Lee filtered image with 3×3 window (f) Proposed Lee filtered image with minimum window size 3×3 and maximum window size 11×11

(a) Original SAR image
Some quantitative measures [3,6] evaluating the performance of various filters are shown in Table 1. Equivalent number of looks (ENL) is used to evaluate the capability of noise reduction, and it is defined by

\[ \text{ENL} = \frac{E^2}{V}, \tag{6} \]

where \( E \) and \( V \) denote the mean and variance of the homogenous region in the filtered image, respectively. Obviously, the larger ENL is, the stronger noise smoothing is. Edge keeping index (EKI) is proposed in [3] and it is used to evaluate the capability of edge preserving. The more closely EKI approaches unit, the stronger edge preserving is. Mean square error (MSE) is used to reflect the performance of filters both in noise suppression and in edge preserving, and it is defined by

\[ \text{MSE} = \frac{1}{N} \sum_{i=1}^{N} (\hat{S}_i - S_i)^2, \tag{7} \]

where \( S \) is the original image, \( \hat{S} \) is the filtered image, and \( N \) is the image size. Obviously, the smaller MSE is, the better filtering performance the filter owns. The qualitative and quantitative experiments above show that the proposed Lee filter is better with higher capability of noise reduction and edge preserving compared to the traditional Lee filter.

Table 1 Some quantitative measures for the simulated image evaluating the performance of various filters

<table>
<thead>
<tr>
<th>Filter Type</th>
<th>ENL</th>
<th>EKI</th>
<th>MSE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean filter</td>
<td>3.5879</td>
<td>0.6284</td>
<td>224.3220</td>
</tr>
<tr>
<td>Median filter</td>
<td>3.2875</td>
<td>0.6932</td>
<td>231.9283</td>
</tr>
<tr>
<td>Lee filter</td>
<td>3.2982</td>
<td>0.7256</td>
<td>203.0899</td>
</tr>
<tr>
<td>Proposed Lee filter</td>
<td>3.6875</td>
<td>0.7064</td>
<td>142.2722</td>
</tr>
</tbody>
</table>

6 Conclusion

A new filtering algorithm for multiplicative noise is presented based on adaptive windowing and local structure detection. This algorithm chooses different window size for homogeneous and heterogeneous area. Point targets are detected by Lopes’ view of statistics classification, and an appropriate window size is chosen by adaptive windowing. Edge orientation is located using gradient masks, and the maximum homogeneous area is chosen as the filtering semi-window for the calculation of local statistics. Experiments on simulated and real SAR image show that the proposed algorithm smoothes noise completely in homogeneous areas as well as in heterogeneous. At the same time, it preserves edges and fine details quite well. In conclusion, this algorithm is a better trade-off between noise suppression and fine detail preserving compared to the conventional fixed-size window filters.

Generally speaking, more computational load is needed using the proposed algorithm with adaptive windowing and local structure detection, which is not convenient for the real-time processing of images. Moreover, the location precision of edge directly depends on the gradient masks used [8]. It is reasonable to believe that other masks such as Prewitt and Sobel gradient masks can get better filtering results. So further research should be focused on the optimization of calculation and use of other edge detection masks.

References


