THE CONTRAST RESEARCH OF THE METHODS OF RESTRAINING THE SPECKLE NOISE OF SAR IMAGES

Zhiyong Wang [a,b] Jixian Zhang [b] Tongxiao Wang [a]

[a] Shandong University of Science and Technology, Tai'an, China – (wzywlp,lcx6088)@163.com

[b] Chinese Academy of Surveying and Mapping, Beijing, China –stecsm@public.bta.net.cn

KEY WORDS: SAR, High resolution, Method, Analysis, Model

ABSTRACT:

There commonly exists speckle noise in the SAR images. It badly disturbs the extraction and interpretation of the information of the objects, influences the application of the SAR images. So it has important meaning to reduce the speckle noise in the SAR images. In this paper, the mechanism and mathematical model of the speckle noise is firstly analyzed. Then the methods of filtering speckle noise is introduced, especially several local region adaptive filters. Two filter models are summarized to direct the construction of the new filter. Then for the typical filter, the contrast tests are carried out. At the last, it brings out a quantitative evaluation index to direct the filtering the speckle noise and the construction of the new filter.

1. Introduce

Because Synthetic Aperture Radar (SAR) can pass the clouds and mist and has the all-weather and full work ability, it has unique superiority with compare with the visible and infrared remote sensing. Therefore, it has been shown more and more bigger application latent capacity in many domains, such as surveying and mapping, geology, hydrology, ocean, ecology, environmental monitoring, glacier charting and military affairs.

Synthetic Aperture Radar (SAR) images are generally corrupted by speckle noise. The presence of the speckle noise in the SAR images is the major obstacle to interpret, classify and analyze SAR images for different application purposes of remote sensing users. The speckle noise badly disturbs the extraction and interpretation of the information of the objects, influences the application of the SAR images. Therefore many speckle noise filters have been proposed for several decades.

2. The mechanism giving rise to speckle noise and mathematical model of the speckle noise

Speckle noise is a physical effect, which occurs when coherent light is reflected from an optically rough surface.

The characteristic speckle effect of radar images results from the destructive and constructive interference among the echoes of individual surface scatters within a resolution cell. Therefore the resultant pixel can differ extremely from its average grey value. These grey value variations between adjacent pixels lead to the typical salt and pepper appearance of SAR images.

The multiplicative speckle model supposes the speckle to be fully developed : Within each resolution cell there must be a large number of scatterers whose phase and amplitude are statistically independence ;the different scatterer amplitudes must belong to the same statistical distribution ;their phases are [0,2π] uniformly distributed .

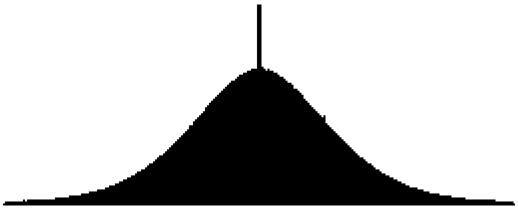
When the ground surface rough degree surpasses the radar wavelength (for example, RadarSAT is 5.6cm and ERS-1/2 is 5.6666cm), and there are many scatters within a resolution cell, the speckle is regarded as fully developed. An appropriate model for fully developed speckle is a multiplicative fading random process F (Ulaby et al .1986 a)

$$I(x,y) = R(x,y) * F(x,y) \qquad (1)$$

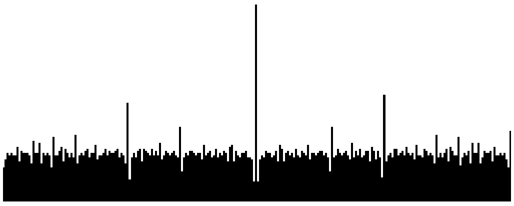
where (x,y) are the spatial azimuth and slant range coordinates of the resolution cell center , I is the observed intensity (speckled observed radiance), R is the random radar reflectivity process (unspeckled radiance). F is a second order stationary random process, statistically independent of R, with unit mean ($M_F = 1$) and whose variance ($V_F = \sigma_F^2$) is inversely proportional to the effective number of looks L .The mean intensity is proportional to the backscattering coefficient σ^0 of the pixel.

Now we use the ERS-1/2 SLC data to produce the real image□imaginary image□phase image□amplitude image(1-look)□intensity image(1-look)□amplitude image(4-looks)□intensity image(4-look). The followings are their histograms.

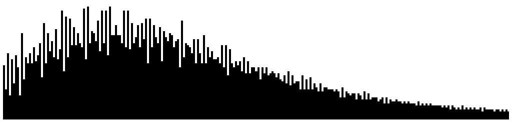
(a) real image



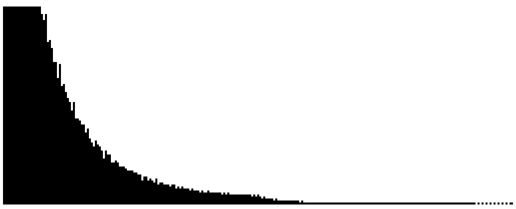
(b) imaginary image



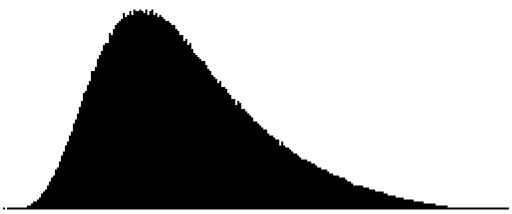
(c) phase image



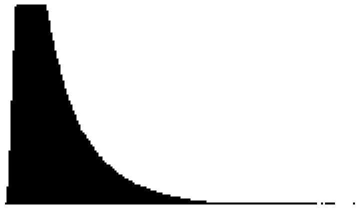
(d) amplitude image(1-look)



(e) intensity image(1-look)



(f) amplitude image(4-looks)



(g) intensity image(4-look)

Fig1 the histograms of different images

Form the above histograms, we can draw the conclusion that the real and imaginary image are both normal distributed; the phase image is uniformly distributed; the amplitude and intensity with single-look are respectively Rayleigh and negative exponential distributed; the amplitude and intensity with 4-look are respectively Gauss and Gamma distributed. This is accordant with the hypothesis or the deduction.

We can use the these statistical characters of SAR images to generate filters.

3. Adaptive speckle filters

Adaptive filter takes a moving filter window and calculates the statistical information of all piexels' grey value, such as the local mean and the local variance. The central pixel's output value is dependent on the statistical information.

Adaptive filters mainly include the Kuan filter□Lee filter□Frost filter□Gamma MAP filter.

3.1 Kuan filter

First of all, a filter for additive noise is developed. Then the multiplicative noise model for radar images is considered. It is based on that the mean square error is minimum(MMSE). The linear MMSE filter estimate is given:

$$\hat{R}(t) = I(t)\cdot W(t) + \bar{I}(t)\cdot(1-W(t)) \qquad (2)$$

where the weighting function W is given by

$$W(t) = [1 - C_u^2 / C_I^2]/[1 + C_u^2] \qquad (3)$$

and where $C_I = \sigma_I / \bar{I}$ is the noise variation coefficient.

3.2 Lee filter

It regards the multiplicative noise model as a linear approximation. And based on the MMSE to estimate. The Lee filter can be describe by (2) with

$$W(t) = 1 - C_u^2 / C_I^2 \qquad (4)$$

3.3 Frost filter

It is estimated by MMSE and based multiplicative noise model. It gives every pixel within the filter window a weighting value, the weighting value is $M = e^{-A*T}$,where

$A = D*(V/I^2)$, T is the distance between the pixel and central pixel; V□I is respectively the variance and mean of filter window.

Frost filter can be described as followed

$$R = \sum_{i=1}^{n}(Pi*Mi)/\sum_{i=1}^{n}Mi \qquad (5)$$

where Pi is the pixel's grey value within the filter window.

3.4 Gamma MAP filter

Gamma MAP filter is firstly proposed by Kuan. He supposed that the probability density distribution of the noise free scene is Gauss distributed. But it is not accordant with the real situation. Then Lopes correct the filter. He supposed that the PDF of the noise free scene and of the noise itself are both Gamma distributed. And he set two thresholds for the filter. The filter can be described as followed

$$R = \begin{cases} I & Ci \le Cu \\ (B*I+\sqrt{D})/(2*\alpha) & Cu < Ci < C\max \\ CP & Ci \ge C\max \end{cases} \quad (6)$$

where, $Cu = 1/\sqrt{NLook}$

$$Ci = \sqrt{VAR}/I$$

$$C\max = \sqrt{2}*Cu$$

$$\alpha = (1+Cu^2)/(Ci^2-Cu^2)$$

$$B = \alpha - NLook - 1$$

$$D = I^2*B^2 + 4*\alpha*NLook*I*CP$$

where, NLOOK is the number of looks; VAR and I are respectively the variance and mean of filter window; CP is the central pixel's grey value; R is the filtered grey value.

If the SAR image is single look, the formula should be corrected

$$R^* = \frac{(\alpha-2)*I^2 + \sqrt{I^2(\alpha-2)^2 + 8\alpha*I*CP}}{2\alpha} \quad (7)$$

4. The base of forming new filter

To form a new filter, we can consider some aspects as followed

4.1 Filter kernel

From analyzing the existing filter algorithms, we can get two common formats for the adaptive filters,

Format 1: $\hat{I}_{ij0} = I_{ij0} \cdot w_{ij0} + m_I(1-w_{ij0})$ (8)

Format 2: $\hat{I}_{ij0} = I_{ij} * w_{ij}$ (9)

Where, $\hat{I}_{ij0}$ is filtered pixel grey value at the center of the filter window; I_{ij0} is the central pixel grey value of the filter window; w_{ij0} is the weighting value calculated from the all pixels' grey value of the filter window; m_I is the local mean calculated from all the pixels of the filter window; I_{ij} is the pixel' grey value within the filter window; w_{ij} is the weighting value for every pixel' grey value within the filter window; * is convolution.

For example, Lee filter and Kuan filter are adopted the Format 1. And Frost filter is adopted the Format 2.

4.2 Sub-windows

We can also divide the filter window to several parts. Every part is called sub-window. We can use the sub-window which the standard deviation is the least to replace the whole filter window. Sub-window can help to improve the ability for preserving edges and detecting point targets. There are some dividing methods to divide the filter window into several sub windows. And different dividing method has different filter effect. So we only choose appropriate dividing method, we can filter the speckle noise in the SAR images.

4.3 Threshold

We can also choose reasonable thresholds to discriminate between homogeneous areas, heterogeneous areas and point targets. For most practical applications, the thresholds can be estimated from the SAR image to be filtered by calculating the local mean and the local variance.

5. A new filter(LogMean)

This method firstly calculates the logarithm operation to the intensity image. By logarithm operation, it can convert the multiplicative noise to the additive noise. According to the multiplicative noise model,

$$I(x,y) = R(x,y)*F(x,y)$$

It can also be simplified: $I = R*F$

After logarithm operation, the model is converted:

$$\ln I = \ln R + \ln F \qquad (10)$$

We can regard lnF as the noise, then the noise is additive. We can use mean filter or Gauss filter to filter the additive noise. At last, we carry out the exponential operation to the filtered logarithmic image. At last, we get the intensity images or amplitude images filtered the speckle noise.

6. The contrast test and Quantitative evaluation

It is very necessary to appraise the filtering effect. The evaluation to filtering speckle noise can be divided into two kinds: the qualitative evaluation and the quantitative evaluation. The qualitative evaluation can be completed through the interpretation with eyes. It is simple and direct, but different people will get different qualitative evaluation. So it is important to make the quantitative evaluation to avoid one's evaluation difference.

6.1 the ability to restrain the speckle noise:

It is mainly evaluated from the Filter Index(FI)□Speckle Noise Index(ß)□Equivalent Number of Looks(ENL).

Filter Index: FI is the ratio of the mean (M) to the standard deviation (SD) of homogeneous areas. It can be described as followed

$$FI = M / SD \qquad (11)$$

The more high FI is, the more strong filter restrains the speckle noise.

Speckle Noise Index(ß): It is the ratio of the standard deviation (SD) to the mean (M) of the homogeneous areas.

$$\beta = SD / M \qquad (12)$$

Equivalent number of looks: ENL is another index which evaluates the ability to restrain the speckle noise. It can be described as follows

$$ENL(I) = 1/\beta^2 \quad \text{(intensity)} \qquad (13)$$

$$ENL(A) = (0.5227/\beta)^2 \quad \text{(amplitude)} \qquad (14)$$

6.2 Mean tonal value preservation:

A good filter should preserve the mean backscattering coefficient value of homogeneous areas. It is to say that the filter should be unbiased estimation. It can be evaluated from the normal mean(NM). The normal mean is the ratio of the mean of the filtered homogeneous area to the mean of original image. It can be described

$$NM = \frac{Mean|_{filtered}}{Mean|_{original}} \qquad (15)$$

where $Mean|_{original}$□$Mean|_{filtered}$ is respectively the mean of homogeneous area of original image and filtered image.

6.3 Texture and Edge preservation:

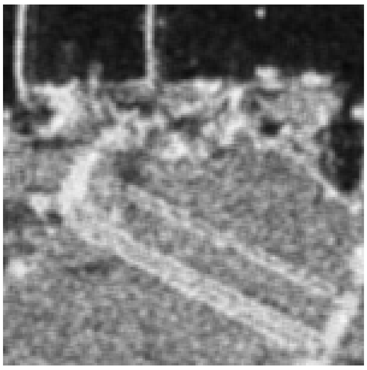
To evaluate the edge preservation, we can use the Edge Keeping Index(EKI). The formula of EKI is as follows.

$$EKI = \sum_{i=1}^{m} G'(w_i) \Big/ \sum_{i=1}^{m} G(w_i) \qquad (16)$$

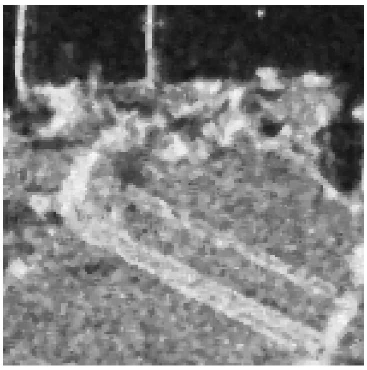
where $G(w_i)$ and $G'(w_i)$ is respectively donated the maximum grey value gradient of original and filtered image in the same window. i=1□m, it donates the number of the sample windows.

The filter window size of the contrast test is 3x3.

(a) Original SAR image

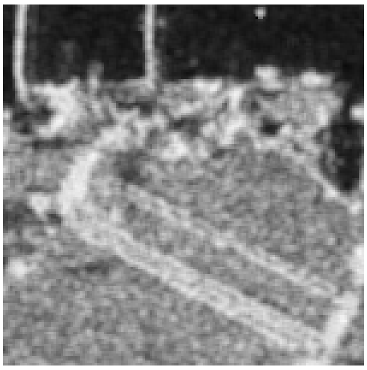


(b) Mean filter(3x3)

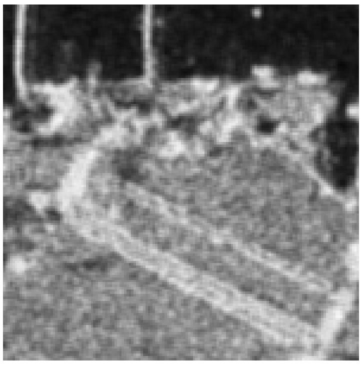


(c) median filter□3x3□

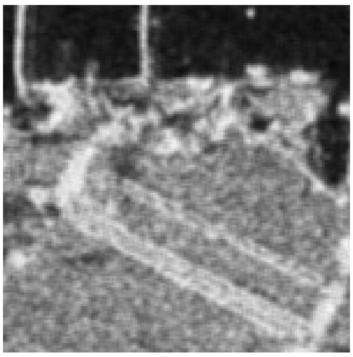
(d) Enhanced Lee filter



(e) Enhanced Frost filter



(f) Gamma MAP filter



(g) LogMean filter

Fig 2 the contrast test results

The following table is the results of quantitative evalution.

Table 1 the results of quantitative evaluation

	ß	FI	ENL	NM	EKI
Original	0.240	4.162	4.732	1.000	1.000
Mean	0.137	7.303	14.571	1.031	0.464
Median	0.158	6.344	10.996	1.047	0.525
Enh Lee filter	0.138	7.266	14.424	1.033	0.613
EnhFrost filter	0.133	7.527	15.479	1.043	0.627
GammaMAP filter	0.133	7.502	15.375	1.041	0.638
logMean	0.139	7.194	14.140	0.867	0.607

7. Conclusion

The most well-known adaptive filters for SAR images are analyzed.From the above contrast test, we can see that the enhanced Lee filter□enhanced Frost filter and Gamma MAP filter not only restrain the speckle noise very well, but also preserve the edge and texture information. We can also choose appropriate thresholds to enhance the adaptive filters.

REFERENCE

J.S.Lee, Digital image enhancement and noise filtering by use of local statistics, IEEE Trans. On Pattern Analysis and Machine Intelligence,1980

J.S. Lee, Refined filtering of image noise using local statistics, Computer Vision, Graphics, and Image Processing,1981

Lopes,R.Touzi,and E.Nezry, " Adaptive Speckle Filters and Scene Heterogeneity ",IEEE Trans. On Geoscience and Remote Sensing, vol.28, No6, pp992-1000,Nov.1990

Lopes A, Touzi R,Laur H. Structure Detection and Statistical Adaptive Speckle Filtering in SAR Images. International Journal of Remote Sensing, 1993, 14(9), 1735-1758

Martin F J, Turner R W. SAR Speckle Reduction by Weighted Filtering. International Journal of Remote Sensing, 1993,14:1759-1774

Smith D M. Speckle Reduction and Segment of Synthetic Aperture Radar Images. International Journal of Remote Sensing, 1996,17(11):2043-2057