Eng. & Tech. Journal, Vol.30, No.13, 2012

Speckle Noise Removal for Synthetic Aperture Radar Imagery Based on Statistics Filters and Nonlinearing Function

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Received on:8/1/2012 & Accepted on: 3/5/2012

ABSTRACT

Synthetic Aperture Radar (SAR) images are contaminated by multiplicative noise, due to the coherence of the radar wavelength, labeled as speckle noise which results in an important reduction in the efficiency of target detection and classification algorithms . In this paper the corrupted pixels are replaced by an estimated value using the simple filter based statistics filters with nonlinear function which are worked at the same time to reduce the speckle noise without blurring edges or other features in SAR imagery. Quantitative and qualitative comparisons of the results obtained by the proposed method with the results achieved from the other speckle noise reduction filters demonstrate its higher performance for speckle reduction with preserving high frequency features (edges) in SAR images.

Keywords: SAR Images, Noise, Speckle Filtering, Adaptive Filter, Edge measure.

ازالة الضوضاء Speckles من الصور SAR على اساس المرشحات الاحصائية والدالة الغير خطية

الخلاصة

صور الرادار الـــ (SAR)غالبا ما تكون مشوهة بالضوضـــاءِ المضـــاعفة Multiplicative Noise بسببِ تماسكِ طولِ الموجة للرادارَ،وتسمى Speckle Noise مما يؤدي إلى تقليل في كفاءةِ كشفِ الهدفِ وخوارزمياتِ التصنيفِ. في هذه البحثِ، النقاط المشوهة تَستبدلُ بقيمة مقدرةِ باستخدام المرشحَ البسيطَ الذي يعمل على أساس المرشحاتَ الإحصائية مع الدالة اللاخطّيـــةِ والتي تعْمُل في الوقتِ نفسهِ في تخفّضَ الضوضاءَ Noise بدون تَشويه الحافاتِ أو الخـــواص ألأخرى للصورةِ المستلمة من الرادارِ. المقارنات الكمّية والنوعية للنَتائِج التي تـــم الحصـــول عليها من الطريقةِ المُقتَرَحةِ مع النَتائِجِ التي أنجزتْ مِنْ مرشحاتِ تقليـــل ضوضـــاءِ الأخـــرى أوضحت ان أداء المرشح المقترح أعلى في تقليل التشويه مع المحافظة على خواص التذبذب العالي (الحافات) في صور الرادار .

INTRODUCTION

Synthetic Aperture Radar (SAR) imagery has become an important source of information about the Earth's surface and has been widely used in many fields, such as ecology [1], hydrology [2] , geology [3] and oceanography [4].

Speckle noise is generated due to constructive and destructive interference of multiple echoes returned from each pixel. As a result, a granular pattern is produced in the radar image which corrupts significantly the appearance of the image objects. Speckle noise can be modeled as multiplicative random noise in spatial domain [5]. More used are two types of filters to a speckle reduction. Low pass filters such as mean or median generally smooth the image are non- adaptive filtering. The second type is adaptive filtering. These filters adapt themselves to the local texture information within a box surrounding a central pixel in order to calculate a new pixel value. Adaptive filters demonstrated their superiority compared to lows pass filters, since they take into account the local statistical properties of the image. Adaptive filters perform much better than low-pass smoothing filters, in preservation of the image sharpness and details while suppressing the speckle noise. Many attempts were made to reduce the speckle noise. Chi and Tray [6] estimate different approaches for reducing speckle noise, including filtering image noise in spatial domain, frequency domain, and time-frequency domain. the Lee,Gamma and Kuan filters can be considered as adaptive-mean filters, and the Frost filter is an adaptive-weighted-mean filter. Meanwhile other filters not derived from speckle models, such as the mean filter, median filter, geometric filter [7].

Recently, few attempts have been made to reduce the speckle noise using wavelet transform as a multi-resolution image processing tool [8]. Speckle noise is a high-frequency component of the image and appears in wavelet coefficients. One common method used for speckle reduction is wavelet shrinkage [9].We suggested a speckle removal based on statistical filters (mean, median) with nonlinear function .This filter can provide speckle removal and target improvement while preserving the resolution of the original image. The suggested filter has been compared with the Lee[10], the Kuan[11] , the frost, the Gamma, the mean, the median filters.Experimental results shows that the present filter yields better results than the others. For the image quality performance measure we used mean square error (MSE) ,edge measurement and signal-to-noise ratio (SNR), as they are better measurements for speckle noise.

SPECKLE NOISE MODEL

Speckle noise is generated due to constructive and destructive interference of multiple echoes returned from each pixel. As a result, a granular pattern is produced in the radar image which corrupts significantly the appearance of the image objects. Speckle noise can be modeled as multiplicative random noise in spatial domain**[**11**].**

A simple model for speckle noisy image has a multiplicative form;

$$I(x,y)=F(x,y)S(x,y) \qquad ....(1)$$

where *I, F* and *S* represent the noisy data, signal and speckle noise, respectively. We chose to enhance the SAR image using addition specked noise as the following:

$$I(x,y)=F(x,y)[1+S'(x,y)] \qquad \mathbf{K}(2)$$
$$I(x,y)=F(x,y)+N(x,y) \qquad \mathbf{L}(3)$$

The original image is represented by *F*, and the values measured by the radar instrument are represented by *I*. The speckle noise is represented by *S*. The parameters *x* and means row and column of the respective pixel of the image. If $S'(x,y) = S(x,y) - 1$ and $N(x,y) = F(x,y)\ S'(x,y)$, we begin with a multiplicative speckle S and finish with an additive speckle *N* [12], which avoid the log-transform, because the mean of log-transformed speckle noise does not equal to zero [13] and thus requires correction to avoid extra distortion in the restored image.

SPECKLE FILTERS

The speckle filters are categorized into two different groups, i.e., non-adaptive and adaptive. Non-adaptive filters take the parameters of the whole image signal into consideration and leave out the local properties of the terrain backscatter or the nature of the sensor. These kinds of filters are not appropriate for non-stationary scene signal. On the other hand, adaptive filters accommodate changes in local properties of the terrain backscatter as well as the nature of the sensor. In these types of filters, the speckle noise is considered as being stationary but the changes in the mean backscatters due to changes in the type of target are taken into consideration. Adaptive filters reduce speckles while preserving the edges (sharp contrast variation). These filters modify the image based on statistics extracted from the local environment of each pixel. Adaptive filter varies the contrast stretch for each pixel depending upon the pixel values the surrounding moving kernel [10].

Some of Nonadaptive Filters :

Mean Filter:

The Mean Filter is a simple one and does not remove the speckles but averages it into the data. Generally speaking, this is the least satisfactory method of speckle noise reduction as it results in loss of detail and resolution. However, it can be used for applications where resolution is not the first concern [14].

Median Filter:

The Median filter is also a simple one and removes pulse or speckle noises. Pulse functions of less than one-half of the moving kernel width are suppressed or eliminated but step functions or ramp functions are retained [14].

Some of Adaptive Filters:

Frost Filter:

The Frost filter replaces the pixel of interest with a weighted sum of the pixels within the nxn moving kernel. The weighting factors decrease with distance from the pixel of interest. The weighting factors increase for the central pixels as variance within the kernel increases. This filter assumes multiplicative noise and stationary noise statistics and follows the following formula [15]:

$$\overline{R}(x,y)=\sum_{i_0=x-\frac{W_s-1}{2}}^{x+\frac{W_s-1}{2}}\sum_{k_0=x-\frac{W_s-1}{2}}^{y-\frac{W_s-1}{2}} K_1K_2C_1^2(x,y).I(l_0,k_0)e^{-K_2C_1^2(x,y)[|x-l_0|+|y-k_0|]} \quad ...(4)$$

Where, $I(l_0,k_0)$= the location of the pixel at the mask of the filter

K_1= the normalization constant

K_2= constant controlling the damping rate

$C_1^2(x,y)$ = the observed coefficient of variation

Lee Filter:

The Lee filter utilizes the statistical distribution of the pixel values within the moving kernel to estimate the value of the pixel of interest. This filter assumes a Gaussian distribution for the noise in the image data. The Lee filter is based on the assumption that the mean and variance of the pixel of interest is equal to the local mean and variance of all pixels within the user-selected moving kernel. The formula used for the Lee filter is [10,14]:

$$\overline{R}(x,y) = I(x,y) \,.\, W(x,y) + \overline{I}(x,y) \,.\, (1-W(x,y)) \qquad ... (5)$$

Where,

$\overline{R}(x,y)$ =the estimated undegraded image

I(x,y) = the observed image

$\overline{I}(x,y)$ = the local mean

W(x,y)= the weighting function for an image model

The weighting function is given for Lee filter by [11]:

$$W(x,y)=1-\frac{C_F^2}{C_1^2(x,y)} \qquad ..(6)$$

Where,

C_F= the coefficient of variation for speckle noise

$C_1(x,y)$ = the coefficient of variation for the observed image.

Kuan Filter:

The Kuan filter transforms the multiplective noise model into signal dependent additive noise model. Then the minimum mean square error criterion is applied to the model. The resulting filter has the same form as the Lee filter but with a different weighting function [10].

$$W(x,y)=\frac{1-\dfrac{C_F^2}{C_1^2(x,y)}}{1+C_F^2} \qquad ...(7)$$

Gamma Filter:

The Maximum A Posteriori (MAP) filter is based on a multiplicative noise model with nonstationary mean and variance parameters. This filter assumes that the original pixel value lies between the pixel of interest and the average pixel values of the moving kernel. The exact formula of the Gamma filter is given by the following equation [11]:

$$\bar{R}(x,y)=\frac{(a_2-N-1).\bar{I}(x,y)+\sqrt{\bar{I}^2(x,y).(a_2-N-1)^2+4a_2.N.\bar{I}(x,y)}}{2a_2} \qquad ...(8)$$

Where**:**

$$a_2=\frac{1+C_F^2}{C_1^2(x,y)-C_F^2} \qquad ....(9)$$

N= is the number of look

α_2= is a controller parameter

Suggested Filter

The suggested filter has a speckle reduction approach that performs spatial filtering in a square-moving window defined as kernel, and also using mean, median filter and slid function at same time to estimate the center pixel. The Proposed method is given by the following equation:

$$\bar{R}(x,y)=\bar{I}(x,y)+k_1\times Err_1+k_1(I(x,y)-\bar{I}(x,y))+k_2(I(x,y)-\bar{\bar{I}}(x,y) \qquad .... (10)$$

$$k_1 = \tanh(a_1 xErr_1) \qquad ....(11)$$

$$k_2=\tanh(a_2 xErr_2) \qquad ....(12)$$

$$Err_1=I(x,y)-(\bar{I}(x,y)+\bar{\bar{I}}(x,y))/2 \qquad ... (13)$$

$$Err_2 = I(x,y) - \bar{\bar{I}}(x,y) \qquad \text{....(14)}$$

Where :

$\bar{\bar{I}}(x,y)$ =the local median

$I(x,y)$ = the observed image

$\bar{I}(x,y)$ = the local mean

k_1, k_2 =the nonlinear functions (gain)

a_1, a_2 = the control factors

The nonlinear functions (tanh(.)) or sliding mode are used to estimate the suitable value of the gain which is relative with error signal for this purpose is detail in [16]. The range of k is from 0 to 1, if the error high the output of this function will be high at this range and if the error small the output of this function will be small at this range function is nonlinear cause are nonlinear for the gain .The a1,a2 are control factors to reduce output for nonlinear function at the range from o to 0.5 which are the best value to removal speckle noise. The structure of the suggested filter is shown in Fig.(1)

-Algorithm Restored Image Input: Gray level image Bmp or Png format with multiplicities noise (noisy image)

Output : De-noisy image

Begin

- **Open noisy image** $I(x,y)$

Step1:Take moving window (3x3) at each time for noisy image

Step2:Calculate mean for 3x3 window.

Step3-Calculate median for 3x3 window.

Step4:Take the center of the same window.

Step5: Calculate E_{rr1} from the Eq.(13) and E_{rr2} from the Eq.(14).

Step6:Find nonlinear functions (gain) k_1, k_2 from the Eqs.(11 &12)

Step7:Apply the Eq. (10) to estimate de-noisy image $\bar{R}(x,y)$

Step8: Increment i,j by one If i equal to M end j equal to N go to end else go to step 1 .

End

Close de-noisy image file

End

SIMULATION RESULTS

Simulations are carried out in MATLAB in order to study the performance of the proposed method are used , two test SAR images of different size used each quantized in 8 bits. The first one is, 366×364 image of the " image1 " as shown in Fig.(2-a) , the second one is 256×256 image of the " image2 ", as shown in Fig,(3-a). original image and a uniformly distributed multiplicative noise with mean zero and variance (0.08, 0.1) are added to the simulated images as shown in Fig.(2-b) and Fig.(3-b).The performance of the suggested filter compared with those of the Gamma filter ,the Lee filter ,the Kuan filter , the Frost filter ,the Mean filter and the Median filter are illustrated by images in Fig.(2-c) to Fig.(2-i) for image1 and Fig.(3-c) to Fig.(3-i) for image2.

In order to evaluate the results of filters quantitatively, the following three parameters are defined and calculated:

- The Mean Square Error is used to find the total amount of difference between two images. A lower MSE indicates a smaller difference between the original image and de noised image. The formula is[15,18]
-

$$MSE=\frac{1}{MN}\sum_{i=1}^{M}\sum_{j=1}^{N}\ (F(i,j)-\overline{R}(i,j)) \qquad \ldots(15)$$

with $F(i,j)$ and $\overline{R}(i,j)$ denoting the values of the original image and the respectively denoised images.

- The signal-noise ratio is an assessment parameter to measure the performance of the speckle noise removal method. The formula is
-

$$SNR=10\log_{10}\frac{\sum F^{2}(i,j)}{\sum(F(i,j)-\overline{R}(i,j))^{2}} \qquad \ldots(16)$$

- The edge measure is also considered for edge preservation .More specifically ,[15] have defined the parameter b as :

$$b=\frac{\sum_{i=1}^{M}\sum_{j=1}^{N}(\Delta F(i,j)-\overline{FX})(\Delta\overline{R}(i,j)-\overline{\Delta\overline{R}})}{\sqrt{\left[\sum_{i=1}^{M}\sum_{j=1}^{N}(\Delta F(i,j)-\overline{\Delta F})^{2}\right]\left[\sum_{i=1}^{M}\sum_{j=1}^{N}(\Delta\overline{R}(i,j)-\overline{\Delta\overline{R}})^{2}\right]}} \qquad \ldots(17)$$

where ΔF and $\Delta \overline{R}$ are the high-pass filter versions of F and $\overline{R}$ respectively , and $\overline{\Delta F}$ and $\overline{\Delta \overline{R}}$ are the mean of the high-pass filter versions of F and $\overline{R}$ respectively, obtained with a 3x3 pixel standard approximation of the sobel operator .The sobel high-pass filter used here for this purpose is detail in [17].
A 3x3 kernel was employed for all statistic speckle filters including Suggested filter. The assessment parameters MSR,SNR and b were applied to the whole image. For Frost filter the damping factor is set to 1 and the control factors in suggested filter is set to a1=0.02and a2=0.12 to set the maximum gain approximated to 0.5 this best range value for estimated the gain value to remove speckle noise . The quantitative results of Table(1) to Table (4) summarize the results of computer simulation to de-noise the image1 and image2 with speckled variance noise are 0.08 and 0.1 respectively, show that the proposed filter can eliminate speckle without distorting useful image information and without destroying the important image edges.

CONCLUSIONS

A simple filter based on statistics filters with nonlinear function to remove speckle noise with edge preservation in digital images is suggested in this paper. A good filter shows lower Mean Square Error, higher Signal to Noise Ratio, and a b closer to one. The proposed filter performs well on two type of images . Experimental results shows that the suggested filter restore the SAR image much better than other speckle noise reduction filters . Furthermore, the knowledge of speckle standard deviation is required in most commonly used speckle filters, and the estimation of speckle standard deviation is not a straightforward task. The proposed filter requires no knowledge of speckle standard deviation.

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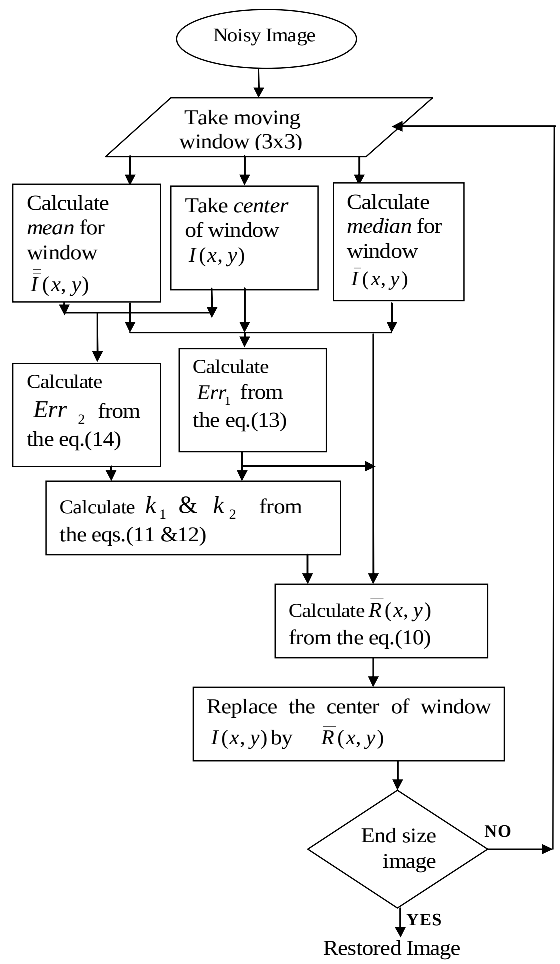
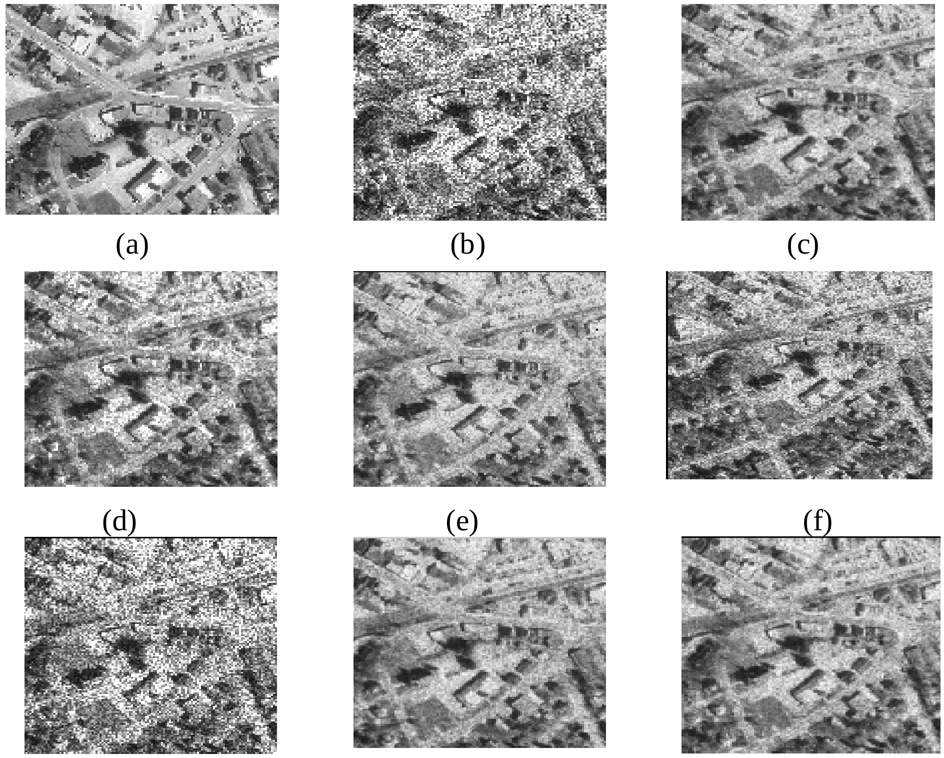


Figure (1)Structure of the Suggested Filter.

Table(1) The evaluation of the filters using 3x3 window for image1 with variance (v=0.08)

Filters	SNR(db)	*b*	MSR
Noisy image	11.6852	0.4075	0.0230
Suggested filter	17.2690	0.4355	0.0084
Gamma filter	16.9601	0.3551	0.0088
Lee filter	13.5329	0.4007	0.0172
Kuan filter	13.5734	0.3988	0.0170
Frost filter	17.2388	0.3558	0.0085
Mean filter	17.2311	0.3534	0.0085
Median filter	15.4230	0.2705	0.0118



(a) (b) (c)

(d) (e) (f)

(g) (h) (i)

Figure (2) (a) The raw image ,(b) Noisy image with v=0.08 ,(c) Mean filter ,(d) Median filter ,(e)Gamma filter ,(f) Kuan filter ,(g)Lee filter ,(h) Frost filer ,(i) Suggested filter

Table (2) The evaluation of the filters using 3x3 window for image1 with variance (v=0.1)

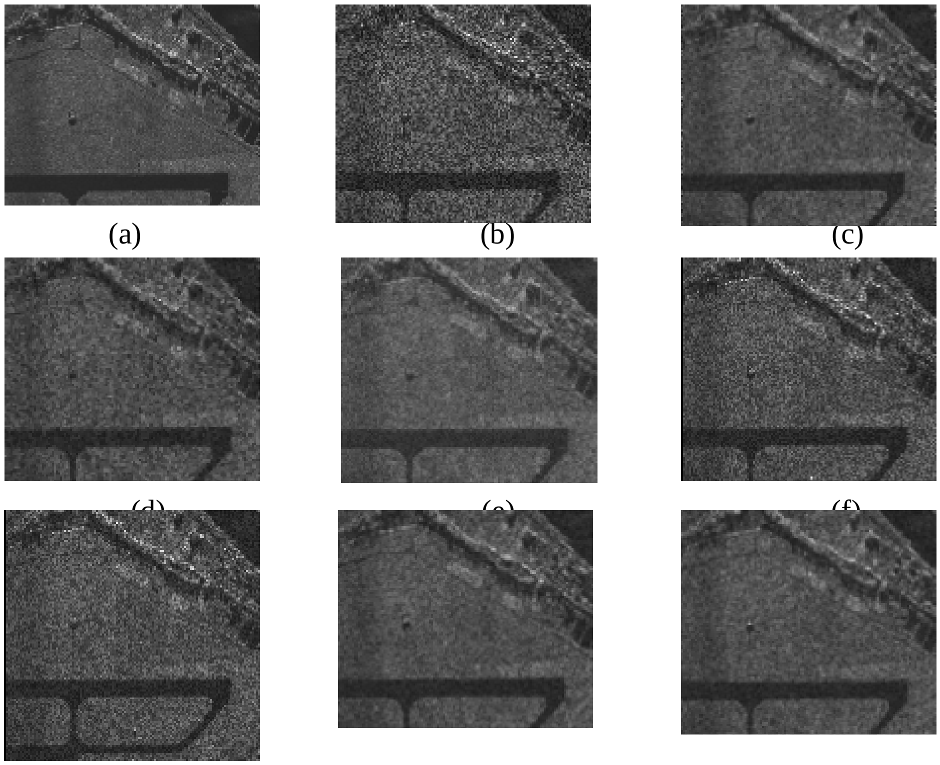
Filters	**SNR(db)**	*b*	**MSR**
Noisy image	10.7876	0.3527	0.0283
Suggested filter	16.7501	0.3893	0.0092
Gamma filter	16.2442	0.3253	0.0101
Lee filter	13.0445	0.2427	0.0168
Kuan filter	13.0620	0.2506	0.0129
Frost filter	16.7037	0.3237	0.0093
Mean filter	16.6954	0.3251	0.0093
Median filter	14.7477	0.2343	0.0134

Table(3) The evaluation of the filters using 3x3 window for image2 with variance (v=0.08)

Filters	SNR(db)	*b*	MSR
Noisy image	10.9779	0.3854	0.0067
Suggested filter	16.8773	0.3404	0.0018
Gamma filter	14.8040	0.2720	0.0034
Lee filter	13.0130	0.3415	0.0101
Kuan filter	15.7425	0.3422	0.0044
Frost filter	16.8411	0.2291	0.0024
Mean filter	16.5632	0.2931	0.0024
Median filter	14.8420	0.2147	0.0033

Table (4) The evaluation of the filters using 3x3 window for image2 with variance(v=0.1)

Filters	SNR(db)	*b*	MSR
Noisy image	10.0234	0.3388	0.0083
Suggested filter	16.4399	0.3277	0.0020
Gamma filter	15.1404	0.3109	0.0039
Lee filter	12.8272	0.3261	0.0050
Kuan filter	15.8490	0.3377	0.0052
Frost filter	16.3992	0.2505	0.0025
Mean filter	16.3918	0.2464	0.0025
Median filter	14.2700	0.1724	0.0037



(a) (b) (c)

(d) (e) (f)

(g) (h) (i

Figure (3) (a) The raw image ,(b) Noisy image with v=0.08 ,(c) Mean filter, (d) Median filter ,(e)Gamma filter ,(f) Kuan filter ,(g)Lee filter ,(h) Frost filer ,(i) Suggested filter