A COMPARISON OF SAR FILTERING TECHNIQUES ON AGRICULTURAL AREA IDENTIFICATION

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ABSTRACT

This study presents a comprehensive evaluation of the most frequently used non-adaptive and adaptive Synthetic Aperture Radar (SAR) filtering techniques called; Mean, Median, Lee, Lee-sigma, Local Region, Frost and Gamma-MAP. Envisat ASAR Precision Image (PI) mode data acquired on August 2008 is used to examine the filtering techniques. Three test sites (~ 4 km^2), located in Karacabey of Bursa in northwest of Turkey are selected. Two of them consist of homogenous agricultural fields and the third one is selected from lake. One of the agricultural test sites has 143 fields where seven different crop types namely; corn, pasture, pepper, sugar beet, tomato, wheat, and watermelon exist. The other agricultural test site contains relatively smaller agricultural fields and it has 386 fields where corn, rice, sugar beet, tomato, wheat, and watermelon are cultivated in it. After correcting the images geometrically, the filtering operations are applied on the amplitude data using 5x5 windows. The filtering performances are evaluated by computing difference of means (MeanDif), difference of standard deviation (StdDif), correlation, and quality factor (Q). If the conditions of these evaluation indicators provide the smallest possible means, standard deviation and the maximum correlation and Q, it can be stated that the filtered image preserves the spectral information of the original image while reducing the speckle effect. Based on this evaluation the most reliable outputs are achieved by applying the Lee filter when compared with the original data. This technique is followed by the results of the Mean, Median, Gamma-MAP and Frost filters.

INTRODUCTION

Microwave signals backscattered from the earth's surface can be in phase or out of phase when received by the satellite sensor. This stage causes random pattern of brighter and darker pixels in the microwave image called *speckle*. This characteristic reduces the interpretability of the microwave images. One of the most widely used method of reducing this limitation is image filtering. Image filtering is a local operation which modifies the original image with the neighboring pixels on the image (Lillesand et.al, 2004). This operation is applied using a window called *kernel*. There are several well-known researchers developing filtering algorithms for the SAR images (Lee 1980; Frost et.al, 1982 and Kuan et.al, 1985). In addition to this, there are also several researchers to examine the results of the filtered products and to evaluate the effectiveness of these methods (Lopes et.al, 1990; Shi and Fung, 1994; Serkan et.al, 2008). Shi and Fung (1994) compare the most widely used filtering methods called Kuan and Frost Filter, Enhanced Lee Filter, Enhanced Frost Filter and Gamma Map filter based on the preservation of point targets, linear features and angular structures. Two water bodies extracted from the ERS-1 image are filtered using the filtering methods in the study. The methods were applied on both the original SAR image and the computer simulated data. Results of the study indicate that the Kuan filter was found to be more accurate for determining point targets of the images. The results point out that the linear features could be separated better than the other filtering methods using the Frost filter. The Frost filter also provided the best results in term of the preservation of the angular structures in the image. Lopes et. al. (1990) also compares the most well-known adaptive filters called Frost, Kuan, Lee and Homomorphic filters on a SAR data and its simulation products. In order to improve the efficiency of the filter, some criteria are included in the filters. It is indicated that the filters reduce the speckle while better preserve the textural information. Herold et.al (2005) aims to improve the classification accuracy of the radar images. They examine various spatial components like speckle reduction while trying to improve the classification accuracy. Five different speckle filters (mean, median, local region, Frost and Lee) are applied on the image using

3x3 and 5x5 windows. They find that the mean and median filters increased the classification accuracy better than the other methods with the 5x5 window size. Serkan et.al.(2008) propose a new adaptive speckle filter called Edge Map-Directed Adaptive Mean (ENDAM) and compare it with the other filtering methods (Mean, Median, Kuan, Lee, Lee-Sigma, Frost, Crimmins, Martin, Nagao and Dong). The filtering operations were performed on a JERS-1 SAR image of Tuzla, Istanbul and a simulated SAR data. The ENDAM filtering method uses a wavelet edge detection algorithm while performing the filtering process, which is the main difference between the proposed method and the other filtering methods. Results indicate that the proposed method provided near results compared with the other filtering results.

The objective of this study is to compare the most widely used SAR filtering methods called Mean, Median, Lee, Lee-Sigma, Frost, Gamma-Map and Local Region filters. Envisat ASAR precision image (I) mode is used to this purpose. The filters are tested on three different sites having almost 5 km^2 extracted from the data. Two out of three belongs to an agricultural area and third one is taken from a lake site. The kernel size of 5x5 is applied on the test sites and results are evaluated four statistical evaluation indicators namely; mean, Std, correlation and Q.

STUDY AREA AND DATA

Three study sites are selected from Marmara Region in Turkey (Figure 1). The sizes of these areas are approximately 5 km^2. Two out of three are selected from one of the most valuable agricultural area called Karacabey Plain in Turkey. Most of the fields in the areas have rectangular shape. The sizes of the fields ranged from 0.1 ha to 9.5 ha and from 0.1 to 13.7 ha for the first and second areas, respectively. There are six crop types filtered in the first region including, pasture, pepper, sugar beet, tomato, wheat, and watermelon. The land cover of the second agricultural region comprises six crop types including corn, rice, sugar beet, tomato, wheat, and watermelon. The third site is selected from the Ulubat Lake near the Karacabey Plain. The study area and the locations of the test sites on the whole area can be seen in figure 1 and 2.

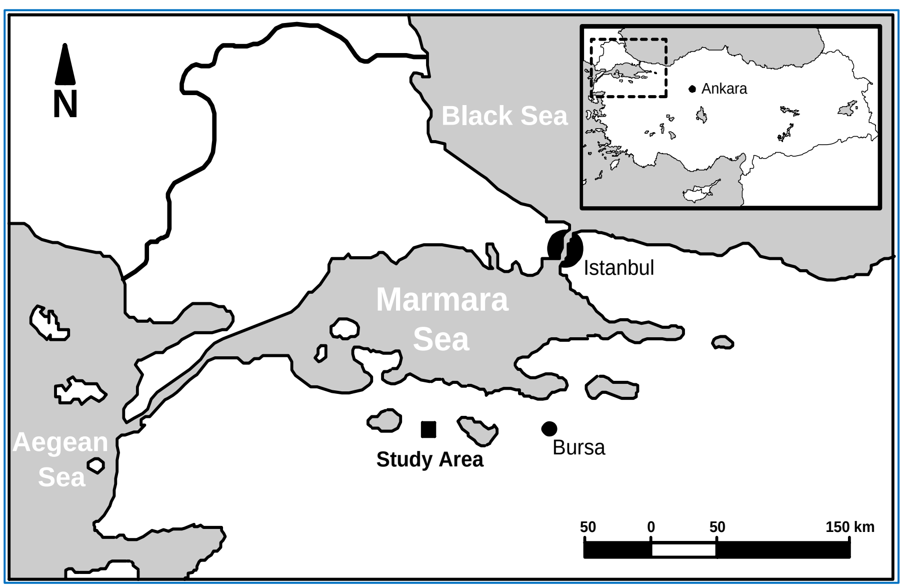

Figure 1. Study Area.

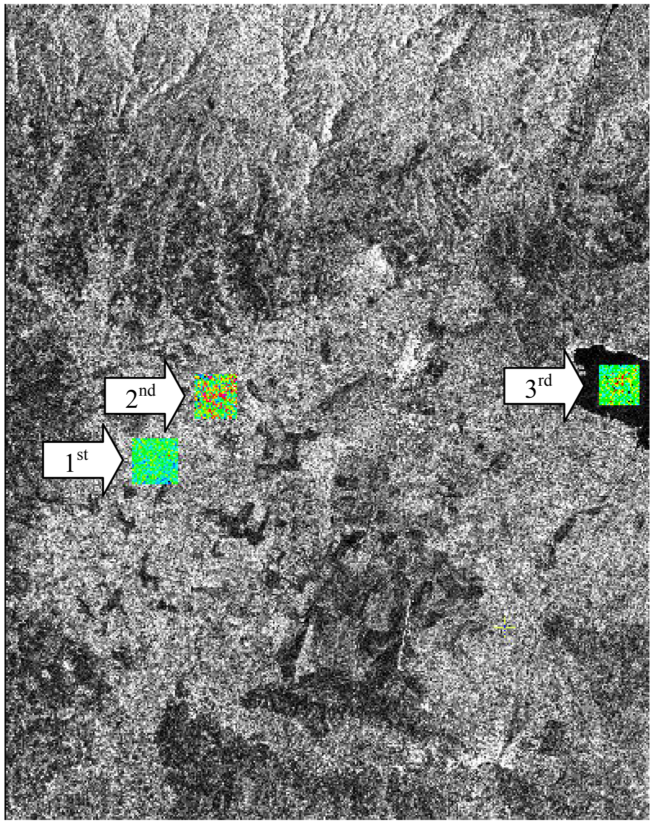

Figure 2. Envisat ASAR data and selected locations.

The Envisat ASAR Precision Image mode used for the filtering operations acquired on 03 August 2008. Table 1 shows the technical summary of the data.

Table 1. Technical summary of the Envisat ASAR data

	Envisat ASAR
Image Type	Image Mode
Processing Level	Level 1b
Spatial Resolution	12.5 m
Wavelength Range	C-band
Frequency Range	5.331 GHz
Polarization	VV
Image Swath	IS7
Swath Width	70km and 56km
Datum	WGS 84
Map Projection	UTM
Zone Number	35

The image was obtained by an ESA Category 1 User project proposed by Akyurek and Ozdarici in 2007. The acquired model provides HH and VV polarization image data with a spatial resolution between 12.5 m and 150 m and coverage of 56x105 km^2. In this study, the VV polarization image is used. Envisat ASAR operates in the C-band and has various incidence angles between 15^0 and 45.2^0. Seven acquisition configurations are available for the Envisat ASAR. The technical characteristics of these configurations can be seen in table 2. Among the seven configuration category, the image used was acquired as IS7 acquisition configuration. The incident angles of the IS7 image vary from 42.5^0 to 45.2^0

Table 2. The configurations types of the Envisat ASAR data

Image Swath	*Swath Width (km)*	*Ground Position (km)*	*Incidence Angle Range*
IS1	105	187-292	15.0-22.9
IS2	105	242-347	19.2-26.7
IS3	82	337-419	26.0-31.4
IS4	88	412-500	31.0-36.3
IS5	64	490-555	35.8-39.4
IS6	70	550-620	39.1-42.8
IS7	***56***	***615-671***	***42.5-45.2***

SPECKLE FILTERING

Speckle, a grainy appearance caused by the interference between waves reflected from microscopic scattering through the terrain, reduces the interpretability of the images therefore it must be balanced with the amount of detail required for the spatial scale and the nature of the particular applications (Medeiros et. al., 2003; CCRS, 2000). There are two methods to reduce the speckle: (i) image filtering, (ii) multi look processing. In this study image filtering processes are examined.

Image filtering is a local operation in which pixel values of an original image are modified using the gray values of the neighboring pixels. It can be categorized two main groups: (i) Non-adaptive speckle filters and (i) adaptive speckle filters.

Non-adaptive filters use the same set of weights to smooth the image over the entire image (e.g. Mean and Median etc.). On the other hand, adaptive filters use weights based on the degree of speckle in the image (Lee, Frost, Kuan, Gamma-Map, Local Region etc.). The smoothing is dependent on the local statistics for the adaptive filters. Therefore, adaptive filters have more capability of preserving the details than the non-adaptive filters (Tso and Mather, 2001). Some of the adaptive filters like Lee, Lee-Sigma and Frost assume a Gaussian distribution while the Gamma-MAP filter assumes a Gamma distribution to decrease the speckle (Lopes et.al. 1990).

In addition to the characteristics of the filtering methods, the window size is also one of the most important factors for smoothing an image. The larger the window size means the larger smoothing. Therefore, it should be decided before smoothing the images based on the analyses.

Mean Filter

The mean filter is a simple filtering method that slides its window (kernel) on the image and replaces the center value in the window with the average (mean) of all the pixel values in the window. It has a speckle reduction capability but it also removes high frequency information in the image. It is one of the most popular non-adaptive filtering methods. Mean filter uses the same set of smoothing for the whole image. Due to the characteristics it ignores the differences in image texture, contrast, etc.

Median Filter

The median filtering procedure is based on ranking the pixel values in the specified window and assigning the median pixel to the center value of the window. Median filtering is another mostly used non-adaptive filtering method. It is more effective than the mean filter. This is because it suppresses the speckle while preserving the characteristics of sharp edges.

Lee Filter

Lee filter is an adaptive speckle filter. It is based on three assumptions:

(i) SAR speckle is modeled as a multiplicative noise that means the brighter the area the noisier it is.
(ii) The noise and the signal are statistically independent to each other.
(iii) The sample mean and sample variance of a pixel is equal to its local mean and local variance found calculated within a window (Lee, 1980; Tso and Mather, 2001).

The assumptions above define the noise model of the Lee filter. In order to apply the filter, two main steps should be performed. The first one is approximating a multiplicative model by a linear model specified by the mean and the standard deviation. The other step is applying minimum mean square error criterion to this model. The filtering procedure can be summarized as follows in a detail manner. First, a window size is determined. Second, the speckle noise mean μ_v and standard deviation σ_v are determined based on the speckle model. If window *i* has N_{pi} pixels, estimates of $\hat{\mu}_v$ and $\hat{\sigma}_v^2$ are computed as follows (Equation 1):

$$\hat{\mu}_v = \frac{1}{N_{pi}} \sum_j z_{ij} \ , \ \ \hat{\sigma}_v^2 = \frac{1}{N_{pi}} \sum_j \left(z_{ij} - \mu_{li}\right)^2 \qquad [1]$$

where

z_{ij} is the return from pixel i in a window i,

$\hat{\mu}_v$ refers to estimate mean intensity of pixels within the window,

N_{pi} means number of pixels in the window

Third, local noise fading mean μ_z and standard deviation σ_z of the pixels within the window are computed. Fourth, noise-free signal standard deviation σ_x is determined. Next, weight coefficient *k* is determined. Finally, the computed $\hat{x}$ value is assigned $\hat{x}$ to the central pixel of the window. The formula of the Lee filter can be seen in equation 2.

$$\hat{\chi} = \left(\frac{z}{\mu_v}\right)\left(\frac{C_z^2 - C_v^2}{C_z^2 + C_v^4}\right) + \left(\frac{\mu_z}{\mu_v}\right)\left(\frac{C_v^2 + C_v^4}{C_z^2 + C_v^4}\right) \qquad [2]$$

where

z is the noise effected image pixel,

μ_v is mean of the noise,

μ_z, mean of the noise affected pixel,

C_z and C_V refer to the coefficient of variations of the noise effected pixel and the noise, respectively.

Lee-sigma Filter

Lee-sigma filter is an adaptive speckle filter. As its name implies, the Lee-sigma filter uses the standard deviation (sigma) to suppress the speckle on an image window. The procedure of the Lee-sigma filter is similar to the Lee filter. It estimates the noise-free signal within the predefined window. The basic difference is that the Lee-sigma filter uses two sigma ranges of the pixels within the window. In this way, the pixels lying outside this range are excluded from the averaging process. The formula of the Lee-sigma filter can be seen in equation 3.

$$\mu \hat{X}_{ij} = \left(\sum_{k=i-n}^{n+1} \sum_{l=j-n}^{n+j} \delta_{kl} z_{kl}\right) / \left(\sum_{k=i-n}^{n+i} \sum_{l=j-n}^{n+j} \delta_{kl}\right) \qquad [3]$$

where

$\delta_{kl} = 1$ if $z_{ij} - 2\sigma_v z_{ij} \leq z_{ij} + 2\sigma_v z_{ij}$

$\delta_{kl} = 0$ otherwise

Frost Filter

The basic idea of the Frost filter is to minimize the mean square error based on the multiplicative noise assumption so that an optional filtering model is to be constructed (Tso and Mather, 2001). It is based on the assumptions of the multiplicative and stationary noise. The pixel of interest is replaced with a weighted sum of the values within the predefined window. The weighting factor is inversely proportional with the distance from the pixel of interest (ERDAS Manual). Its calculation is performed based on the formula below (Equation 4, 5 and 6).

$$DN = \sum_{nxn} K\alpha e^{-\alpha|t|} \qquad [4]$$

where

$$\alpha = \left(4 / n\sigma^{-2} \right) \left(\sigma^2 / \bar{\mu}^2 \right) \qquad [5]$$

K is a normalization constant

$\bar{\mu}$ is a local mean

σ means local variance

$\bar{\sigma}$ refers to image coefficient of variation value

n is the moving window size

$$|t| = |x - x_0| + |y - y_0| \qquad [6]$$

Gamma Map Filter

The Gamma- Map filter assumes that the scene reflectivity of an image has a Gaussian distribution. Therefore, this filter uses a priori knowledge of the probability density function (PDF) of the scene when suppressing the speckle of the image (Shi and Fung, 1994). Under this assumption the computation of the Gamma Map filter can be performed as follows (Equation 7).

$$\hat{\mu}^3 - \mu \hat{\mu}^2 + \sigma \left(\hat{\mu} - DN \right) = 0 \qquad [7]$$

where

μ is the original image variance

$\hat{\mu}$ is the expected value

σ refers to original image variance

DN is the input value

Local Region Filter

The Local Region filter compares the variance values of the regions surrounding the pixel of interest (Equation 8). While doing this, it divides the moving window into eight regions based on angular position. The central pixel of the window is then replaced with the mean values within the region with the lowest variance (Sheng and Xia, 1996).

$$\sigma^2 = \sum \left(DN_{xy} - \mu \right) / n - 1 \qquad [8]$$

EVALUATION INDICATORS

Quality of all the filtered products (3x3, 5x5, 7x7, and 9x9) was evaluated quantitatively using mean, standard deviation, correlation and quality factor. When evaluating the filtered products, preserving the radiometric quality of the data was taking into consideration. That means if the radiometric quality of the original and fused images is similar to each other, it can be stated that their global statistical parameters should be very similar (Karathanassi *et al.*, 2007). If the conditions of these evaluation indicators provide the smallest possible means, standard deviation and the maximum correlation, the filtering performance can be thought as good. The computations of the correlation and Q measures can be seen in equation 9, 10 and 11.

Correlation

Correlation values were computed between the original and filtered products based on the equation below.

$$\delta_{f.o} = \frac{\mathrm{COV}_{f.o}}{\partial_f \, x \, \partial_o} \qquad [9]$$

where

$\mathrm{COV}_{f.o}$ refers to covariance of the original and filtered image

∂_o and ∂_f are the standard deviations of the original and filtered images, respectively.

Quality Factor (Q)

On the other hand the Q is an important test measures which is used to reduce the standard deviation to decrease the variations in the uniform areas. The computation of the quality factor is given in equation 10 and 11.

$$Q = \frac{\lfloor \mu_{shift} \rfloor}{L_0 x \left(\sigma^2\right)_f} \qquad [10]$$

where

$\mu_{shift} = \mu_o - | \mu_0 - \mu_f |$

μ_o is the mean value of the original image

μ_f is the mean value of the filtered image

$\left(\sigma^2\right)_f$ is the variance of the filtered image

L_0 is the equivalent number of looks value of the original image which is computed as:

$$L_0 = \frac{\mu_0^2}{\sigma_0^2} \qquad [11]$$

where

μ mean value,

σ is the variance of the image data.

The Q value is always equal to 1 for the original image. Any change in the mean value will reduce the Q. This can be evaluated as reduction in filter capability. A decrease in the variation for the filtered image will increase the value of Q. That means the higher the Q value, the stronger the speckle reduction (Serkan et.al, 2008).

RESULTS AND DISCUSSION

Seven different filtering methods called Mean, Median, Lee, Lee-sigma, Frost, Gamma-Map and Local Region were examined in the study. The filters with 5x5 kernels were applied on three scenes extracted from an Envisat ASAR image taken on August 2008. Six criteria namely mean, Std, mean difference (MeanDif), Std difference (StdDif), correlation and Q were selected to evaluate the effectiveness of the results. Based on the table 3, it was indicated that the Lee filtered image provided similar mean value with the original image and it was reduced Std value of the original image around 1.19. Its correlation value was found relatively high (0.73) when compared with the Mean, Median, Frost, Local Region and Gamma-Map filters. The highest Q value was computed for the Lee filter for the first test site. These numerical indicators showed that the Lee filter yielded the best results in the other filtering methods. Although the Mean and Median filters exhibited closer results to the mean value of the original image and high StdDif values, the correlation and Q values were found relatively low when compared with the Lee filter. The Gamma-MAP filter also revealed satisfactory results although its mean values is low (5.34) than the original image. The Lee-Sigma filter exhibited relatively low results but unexpectedly it has the highest correlation value (0.81). The poorest results were obtained for the Local Region filter. Although the mean and median value of the image filtered by the Local Region filter were high enough, the correlation and Q value of this filter is very low.

Table 3. Filtering results for the first test site

	5x5 Window			
	MeanDif	*StdDif*	*Correlation*	*Q*
Original (FirstSite)	**-**	**-**	**-**	**1**
Mean	0	0.98	0.64	2.97
Median	0.09	0.92	0.64	2.65
Lee	0.01	1.19	0.73	2.8
Lee-Sigma	0.3	0.82	0.81	2.15
Frost	0.01	0.9	0.74	2.64
Local Region	0.13	0.63	0.53	1.8
Gamma-MAP	0.84	1.1	0.8	2.67

When the second agricultural test site was examined, it was observed that the Lee and Gamma-MAP filters provided the highest results relative to the other filtering methods (Table 4). The Lee filter preserve the mean of the original image while the mean value of the Gamma-MAP filter was rather low (5.34) from the original value. The highest Q values of 2.46 and 2.67 were computed for the Gamma-MAP and Lee filters, respectively. The results of the Lee and Gamma-MAP filters were followed by the Mean and the Median filters. Except for the mean values of the filters, the other indicators were provided similar results. The mean value of the Mean filter was exhibited similar result with the original image (6.02) while the result of the mean value (5.92) for the Median filter was found low. Acceptable results were achieved by the Frost filter. The values of the Lee-Sigma filter were found to be less efficient. Similar to the first agricultural test site, the worst results were found for the Local Region filtering method. The correlation and the Q values were computed as 0.58 and 2.67, respectively.

Table 4. Filtering results for the second test site

	5x5 Window			
	MeanDif	*StdDif*	*Correlation*	*Q*
Original (Second Site)	-	-	-	**1**
Mean	0	0.91	0.68	2.25
Median	0.1	0.87	0.68	2.35
Lee	0.01	0.88	0.76	2.46
Lee-Sigma	0.28	0.78	0.81	1.97
Frost	0.01	0.83	0.77	2.03
Local Region	0.17	0.6	0.58	1.46
Gamma-MAP	0.68	1.19	0.81	2.67

The third site consists of pixels that are located on the Ulubat Lake which represents a more homogenous area than the other test sites. Therefore, the comparison of the filters using this site can be more realistic than the others. When the third site was examined, it was observed that similar to the first and the second agricultural test sites the Lee filter was superior to the other filtering methods (Table 5). It was provided a better preservation of the mean value (1.99) and a high StdDif (0.31) value. While the correlation value of the Lee filtered image was computed as 0.56, the Q value of it was found rather high (2.82). Acceptable results were obtained for the Mean and the Median filters although their correlation values were computed low (0.45). The Frost and the Gamma-MAP filters were also found effective. The Lee-Sigma and Local Region filters exhibited the poorest results when compared with the other filtering methods. The Lee-Sigma filter provided relatively high correlation value (0.71) and its Q value was found to be 1.67. The correlation value of the Local Region filter was computed as 0.41 while the Q value of this filter was 1.71.

Table 5. Filtering results for the third test site

	5x5 Window			
	MeanDif	*StdDif*	*Correlation*	*Q*
Original (Lake Site)	-	-	-	**1**
Mean	-0.03	0.34	0.44	3.17
Median	-0.01	0.33	0.45	3.09
Lee	-0.01	0.31	0.56	2.82
Lee-Sigma	0.16	0.12	0.76	1.67
Frost	-0.01	0.27	0.65	2.38
Local Region	0.03	0.19	0.41	1.72
Gamma-MAP	0.09	0.32	0.56	2.71

CONCLUSION

Aim of this paper is to examine the most widely used filtering methods and to decide the best method for agricultural areas. Three different test sites consisting of two agricultural areas and a small part of lake were selected to apply the filtering performances. The filtered products were evaluated based on the MeanDif, StdDif, Correlation, and Q indicators. The numerical results indicated that the Lee filter performs much better for preserving the spectral characteristics of the original image while reducing the speckle. The results of the Mean, Median, Gamma-MAP and Frost filters were found satisfactory. The Lee-Sigma filter could not provide similar results with the Lee filter and the results of those filters were found low. The poorest results were obtained for the Local Region filter. Although the analyses exhibited consistent results for three test sites, further quantitative evaluations (e.g. edge preserve, texture) should be added to the analyses in order to examine the filtering methods more reliably.

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