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Comparison of Various Speckle Noise Reduction Filters on Synthetic Aperture Radar Image

[1,2,*]Ardhi Wicaksono Santoso, [2,3]Luhur Bayuaji, [4]Lim Tien Sze, [5]Habibah Lateh, [2]Jasni Mohamad Zain
[1]Department of Electronics and Informatics, Sekolah Vokasi, Universitas Gadjah Mada, Yogyakarta, Indonesia
[2] Faculty Computer System and Software Engineering, Universiti Malaysia Pahang, Malaysia
[3] IBM Center of Excellence, Universiti Malaysia Pahang, Malaysia
[4] Faculty of Engineering and Technology, Multimedia University, Malaysia
[5] School of Distance Education, University Sains Malaysia, Malaysia
[*] Corresponding Author

Abstract
Synthetic Aperture Radar (SAR) image with its advantages, is becoming popular than the optical image in earth observation using the remote-sensing techniques. The SAR image has a high resolution and not influenced by weather conditions either day or night. SAR's image formation process led to speckle noise; it causes difficulties during the process of interpretation and analysis of SAR images. Thus, speckle noise reduction needs to be deployed prior to the use of the SAR images. The ideal speckle filter has the capability of reducing speckle noise without losing the information and content, while preserving the edges and features. To date, various noise filters have been designed for different purposes and different capacities. In this study, we discussed four filters, namely Lee, Frost, Median and Mean filter. Those four filters are analyzed and compared based upon the quality parameter and statistical performance using SAR sample image respectively. We are analyzing quality parameter and comparing statistical performance of Lee, Frost, Mean and Median filters for SAR sample image. The results show Mean Square Error (MSE), Average Difference (AD), Peak Signal to Noise Ratio (PSNR), Signal to Noise Ratio (SNR) and Structural Similarity Index Measure (SSIM) value that generated on SAR image with four different areas by Frost filter performs better than the other filter. Visual interpretation of the de-speckle image that filtered with Frost filter shows sharpens edge and preserved texture to the SAR image.

Keywords: synthetic aperture radar (SAR), speckle noise, de-speckle, image filter, image processing

INTRODUCTION

Synthetic Aperture Radar (SAR) is a type of sensor used for observation and characterization of Earth's surface [1]. SAR sensor has several advantages such as the ability to produce high spatial resolution images, capable to observe in the day and night and all-weather condition [2]. SAR is categorized as an active sensor, it sends electromagnetic waves into the target in earth surface and processes the signals that reflected from the target by coherently [3].

Nevertheless, the SAR image suffers from additive and multiplicative noise. The additive noise comes from the receiver thermal noise. However, the image is mostly affected by multiplicative noise compared to additive noise. This multiplicative noise is also known as speckle noise and causes difficulties on interpretation, analyzing, detection and classification process of the SAR image [2,3,4]. Consequently, required a pre-processing step in SAR image before the advanced uses. The speckle noise reduction is an important step to do that. The aim of a speckle noise reduction is to remove noise by smoothing the regions of image while keep preserve on texture information and edges. Various researchers have conducted the speckle noise reduction with several proposed methods with their own strength and limitation [5].

In this study, we apply various filters, namely Frost filter [6,7,8], Lee filter [6], [9,10], Median filter [6], [11,12] and Mean filter [6], [11,12], into the SAR image. These adaptive filters are the most commonly used in SAR imagery pre-processing. There are many types of SAR images [13] that related to this study [1], [3] used Polarimetric SAR (PolSAR) image in their work, [5] used AirSAR image in their work, and in this study we apply that filter into ALOS-PALSAR image. The filters perform on 3x3 size of the moving kernel window and applied into several earth surface type surfaces. The evaluation of filter performance includes several criteria such as, preservation of the mean, reduction of the standard deviation, preservation of the edges and texture preservation. The main objective of the work presented in this study is to select most suitable and the best filter for pre-processing of ALOS-PALSAR's original image that will use in the future work.

SPECKLE NOISE

Speckle noise is generated during the process of creating the SAR image, that cause by coherent radiation. This noise is an undesired effect that degrades the quality of images, and mostly categorized as multiplicative noise [14]. SAR images also have statistical property that mostly evolved from multiplicative noise model. This image can be formed as multiplicative noise models as follows [10]:

$$I(t) = R(t).v(t) \quad (1)$$

where *I (t)* is the noise-affected signal, *R(t)* is original image or the radar backscatter property without noise of ground targets and *v(t)* is speckle noise and it is independent with *R(t)*. SAR speckle that generated by a zero-mean random phase of echo signals, causes the mean value of v(t) is one, and its variance is relevant with the equivalent number of SAR images [10].

The existence of speckle noise in SAR image will distract detection and classification process [4]. Thus, speckle noise must be eliminated during the pre-processing of SAR images.

This technique becomes an essential procedure in most of the target detection and recognition systems. However, it may lead to the loss of image details such us texture information or edges [14].

MATERIAL AND METHODS

Speckle Filtering

Filtering is a technique to remove unwanted information from an image prior to the next step of the image processing [15]. The main objective of speckle filtering is removing noise in the uniform area, preserve texture and enhance the edge without changing features, as well as providing a good visual appearance. Speckle filtering works by the movement a kernel window over each pixel on the image along the entire image. The kernel window moves and applies a mathematical calculation and also substitutes the value of the window central pixel. As a result, the smoothing effect and visual appearance reduced speckle is achieved [6].

Many researcher apply Frost filter [6,7,8], Lee filter [6], [9,10], Median filter [6], [11,12] and Mean filter [6], [11,12], suitable for the type of noise filter with salt and pepper noise which has properties similar to speckle noise in general SAR images. As mentioned previously, there are four types of filter methods that are implemented in this study. Thus, this section describes a short definition and mathematical formula of speckle reduction filters.

Frost Filter

The Frost filter [2,3] is an adaptive and exponentially weighted averaging filter based on the coefficient of variation which is the ratio of the local standard deviation to the local mean of the degraded image. This filter response varies locally with the coefficients of variation. Thus, at high coefficient variation, the filter attempts to preserve sharp features by retaining its original pixel value while at low coefficient variation, the filter is more average-like. This filter is can be implemented based on the formula below:

$$DN = \sum_{n\,x\,n} k\alpha e^{-\alpha|t|} \tag{2}$$

where k is a normalization constant, α is $(4/n\sigma'^2).(\sigma^2/\bar{I}^2)$, $\bar{I}$ is the local mean, σ is the local variance, σ' is image coefficient of variation, $|t| = |X - X_0| + |Y - Y_0|$ and n is the moving window size.

Lee Filter

The Lee filters [6], [10] compute a linear combination of the center pixel intensity in a filter window with an average intensity of the window for removing speckle noise. This filter is based on the minimum mean square error (MMSE), and speckle free image is produced based on the following equation:

$$\hat{R}(t) = \bar{I}(t) + W(t)(I(t) - \bar{I}(t)) \tag{3}$$

where $\hat{R}(t)$ is image value after being filtered and it's also the estimated value of $R(t)$, $\bar{I}(t)$ is the mean value of $I(t)$, and the weighting function $W(t)$ is given by

$$W(t) = 1 - \frac{C_v}{C_I} \tag{4}$$

where C_v is the variance coefficient of noise-affected image with standard deviation, and C_I is the variance coefficient of noise-free of local image with standard deviation.

Median Filter

The median filter [6], [11,12] including is a spatial non-linear filter. For reducing pulse or speckle noise, this filter works by calculating the median value of its neighbors in the window for replacing the middle pixel value in the window. This filter is can be implemented based on the formula below:

$$\hat{f}(x,y) = \underset{(s,t)\in S_{xy}}{median}\{g(s,t)\} \tag{5}$$

where *g(s,t)* given original image, S_{xy} represent the set of coordinates in rectangular image windows.

This filter is capable to remove impulse or short duration noise, but it is not well suited for speckle noise. The common problems of this filter, its causes edge blurring, erasing thin linear features and object shape distortion.

Mean Filter

Mean filter [2], [11,12] is a simple filter. This filter works by calculating the mean value of the pixels of neighbor window. Then the mean was used to replace the center pixel value window. This filter noise smoothing ability is good, but it also causes a reduction of detail and resolution. This filter is can be implemented based on the formula below:

$$\hat{f}(x,y) = \frac{1}{m.n}\sum_{(s,t)\in S_{xy}} g(s,t) \tag{6}$$

where *m.n* is kernel windows size, *g(s,t)* given original image, S_{xy} represent the set of coordinates in rectangular image windows.

Evaluation Performance of Filter

In order to measure the performance of filter, seven measurement methods have been used. Those methods are Mean Square Error (MSE), Average Difference (AD), Speckle Index (SI), Peak Signal to Noise Ratio (PSNR), Signal to Noise Ratio (SNR) [17,18,19], Structural Similarity Index Measure (SSIM) [21] and Equivalent Number of Looks (ENL) [13], [20]. The measurement methods will show the efficiency and ability of filter to enhance image. The following established performance metrics [15,16,17,18,19,20], aimed at evaluate the performance of the speckle noise reduction algorithm in removing noise and maintain the image information. The detail about each method can be found in this following section.

Mean Square Error (MSE)

This parameter is used to find the differences of the original image and de-noised image. The values indicate the differences between the original and filtered image. MSE is calculated as follows [17,18,19]:

$$MSE = \frac{1}{MN}\sum_{i=1}^{M}\sum_{j=1}^{N}\left(X_{i,j} - X'_{i,j}\right)^2 \quad (7)$$

where M x N is size of image X. The highest value of this parameter is 255, and that mean the original and filtered image completely dissimilar. The lowest MSE values are zero, and this means better image quality.

Average Difference (AD)

This parameter is used to find the differences between original and filtered image divided by the size of the image. It is calculated as follows [17,18,19]:

$$AD = \frac{1}{MN}\sum_{i=1}^{M}\sum_{j=1}^{N}\left|\left(X_{i,j} - X'_{i,j}\right)\right| \quad (8)$$

The highest value for this parameter represents to dissimilar image, and its opposite represents to similar images.

Speckle Index (SI)

The parameter is used to measure of speckle reduction in terms of average contras of the image. The SI defined as follows [17,18,19]:

$$SI = \frac{1}{MN}\sum_{i=1}^{M}\sum_{j=1}^{N}\frac{\sigma(i,j)}{\mu(i,j)} \quad (9)$$

where $\sigma(i,j)$ and $\mu(i,j)$ are the standard deviation and means corresponding to the neighbor domain, respectively.

The highest value of SI represents to dissimilar image, and its minimal value represents to similar images or improved image quality.

Peak Signal to Noise Ratio (PSNR)

This parameter represents the ratio between the maximum possible power of the signal and the noise image. It is measurement of the performance of the speckle noise reduction. It calculated as follows [17,18,19]:

$$PSNR = 10\,log_{10}\left(\frac{(2^n - 1)^2}{MSE}\right) = 10\,log_{10}\left(\frac{255^2}{MSE}\right) \quad (10)$$

Better image quality is indicated by a higher PSNR value. Higher PSNR means more noise removed. Identical pictures occur when the MSE value is zero, and causes undefined the PSNR value.

Signal to Noise Ratio (SNR)

This parameter represents the ratio between the original and image de-noise. It evaluates the speckle reduction in the case of multiplicative speckle noise and calculated as follows [17,18,19]:

$$SNR = 10\,log_{10}\frac{\sum_{i=1}^{K} S_i^2}{\sum_{i=1}^{K}\left(\hat{S}_i - S_i\right)^2} \quad (11)$$

Higher SNR values show that the filtering effect is better, and filtered image quality is much higher.

Structural Similarity Index Measure (SSIM)

This parameter is used for measuring the similarity between two images [21]. The index is a reference to measure of image quality based on an initial distorted image as reference. The measurement should provide a good approximation to perceive image distortion. This parameter is defined as follows:

$$SSIM = \frac{(2\mu_x\mu_y + C_1)(2\sigma_{xy} + C_2)}{(\mu_x^2 + \mu_y^2 + C_1)(\sigma_x^2 + \sigma_y^2 + C_2)} \quad (12)$$

where μ_x the average of x, μ_y the average of y, σ_x^2 the variance of x, σ_y^2 the variance of y, σ_{xy} the covariance of x and y, $C_1 = (k_1L)^2$, $C_2 = (k_2L)^2$ two variables to stabilize the division with weak denominator, L the dynamic range of the pixel-values (typically this is $2^{\text{bit per pixel}} - 1$) and $k_1 = 0.01$ and $k_2 = 0.03$ by default.

The resultant SSIM index is a value between -1 and 1, and value 1 is only reachable in the case of two identical sets of data or better image quality.

Equivalent Number of Look (ENL)

This parameter represents the equivalent to the number of independent intensity values averaged per pixel. It is often applied not just to describe the original data but also to characterize the smoothing effects of post-processing operations such image filtering [13], [20]. The ENL for a homogeneous region of an image is the ratio between the mean squared to the variance. The ENL is defined as follows:

$$ENL = \frac{mean\,(F)^2}{var\,(F)^2} \quad (13)$$

where $F(x,y)$ given the filtered image. It is therefore clear that the higher the ENL value for a filter, the higher the efficiency of improving the signal-to-speckle ratio over homogeneous areas that mean image quality is better.

RESULT AND DISCUSSION

The experimental result is discussed throughout this section. These result obtained by applying speckle reduction filters that described earlier in ALOS-PALSAR images with a size of 317 x 317 pixels. ALOS-PALSAR image area is selected in four different area. The selected areas are urban area, vegetation area, hilly area and sea area. This four different areas, represent most of the area on the Earth's surface. ALOS-PALSAR image filtered using Lee, Frost, Mean and Median Filter, by using 3x3 windows size.

Evaluation measurements performed for each de-speckle image, which is used to compare the effectiveness of filter. In addition, it is important to evaluate the performance of some speckle reduction filter.

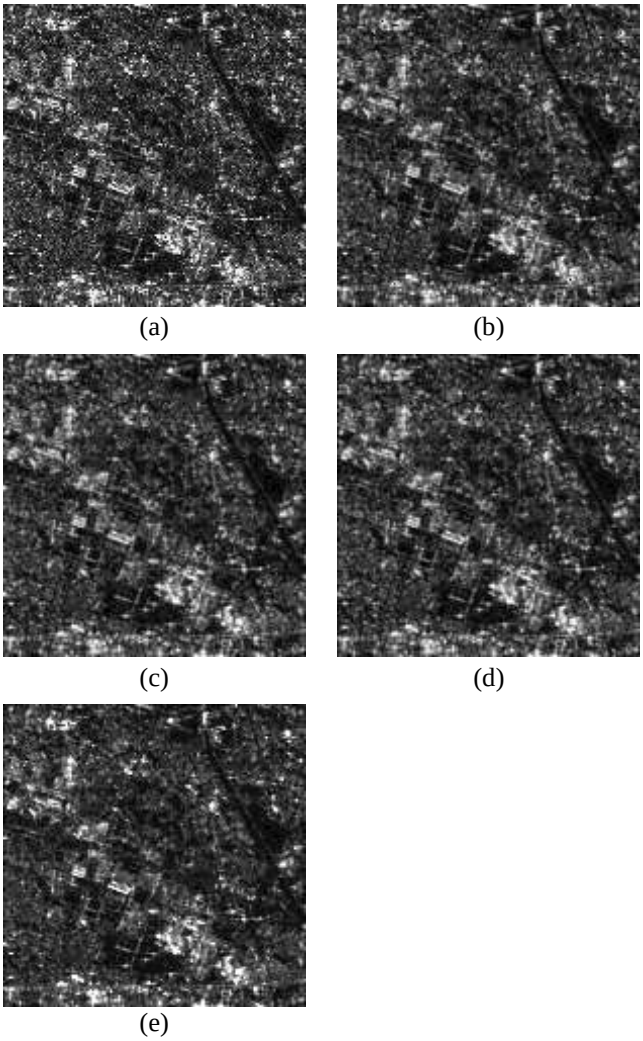


Figure 1: Filtered ALOS-PALSAR image of Urban area by using various filter: (a) Original image, (b) Frost, (c) Lee, (d) Mean, (e) Median.

Figure 1 shows the filtered image of Urban Area by various filters. Figure 1.a represent the original image of Urban area. Figure 1.b is the filtered image by Frost filter. Figure 1.c shows the filtered images by Lee filter. Figure 1.d is the filtered image by Mean filter and Figure 1.e shows the filtered image by Median filter. In addition, the performance of the filters is measured based on image quality parameters of the filtered images. The evaluation performance of the filters for Urban area shows in Table 1.

Table 1: Measurement Methods of the Various Filters for Speckle Noised in Urban Area image

Filter	**Measurement Method**						
	MSE	**AD**	**SI**	**PSNR**	**SNR**	**SSIM**	**ENL**
Frost	**73.95**	**10.64**	0.61	**18.86**	**5.15**	**0.68**	2.65
Lee	76.86	11.73	**0.59**	17.94	4.98	0.58	**2.80**
Median	83.44	12.51	0.69	17.76	4.62	0.57	2.09
Mean	77.79	11.96	0.60	17.86	4.93	0.58	2.79

*bold indicate better value/performance

The data in Table 1 shown, de-speckle image filtered with Frost filter have 73.95 in MSE value and 10.64 in AD value or the lowest value than other filters. However, the lowest value of SI generated by Lee filters de-speckled image of 0.59. The low MSE, AD and SI value means to have better image quality.
De-speckle image filtered with Frost filter has 18.86 in PSNR value, 5.15 in SNR value and 0.68 in SSIM value or the highest value than other filters. But for ENL highest value of 2.80 is produced by Lee filter de-speckled image. The high ENL, PSNR, SNR and SSIM value mean to have better image quality also as described earlier.

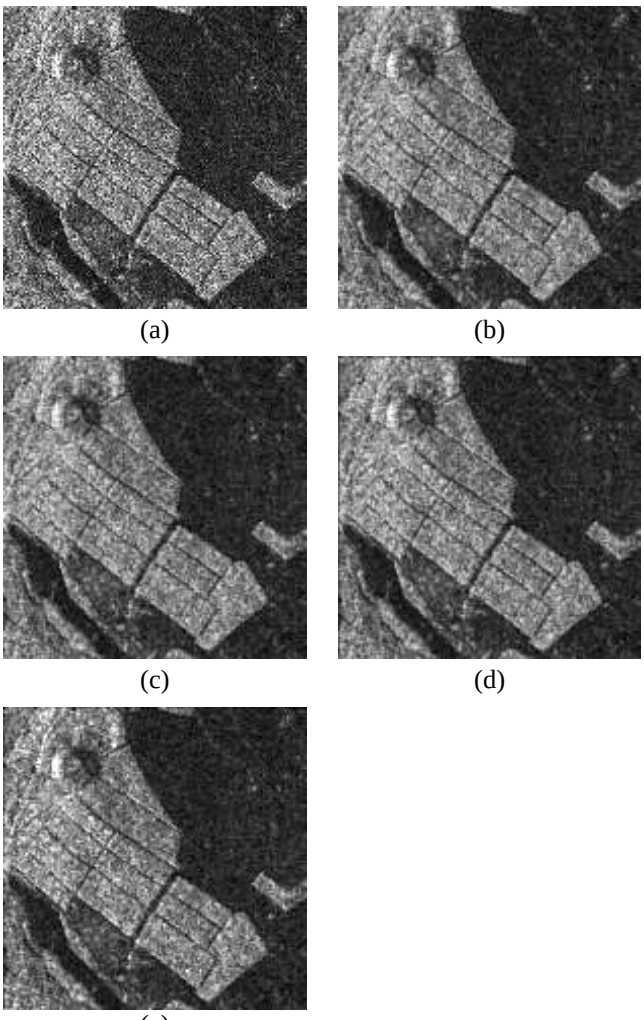


Figure 2: Filtered ALOS-PALSAR image of Vegetation area by using various filter: (a) Original image, (b) Frost, (c) Lee, (d) Mean, (e) Median

Figure 2 shows the filtered image of Vegetation Area by various filters. Figure 2.a represent the original image of Vegetation area. Figure 2.b is the filtered image by Frost filter. Figure 2.c shows the filtered images by Lee filter. Figure 2.d is the filtered image by Mean filter and Figure 2.e shows the filtered image by Median filter. In these images, the performance of the filters also measured based on image quality parameters of the filtered images. Table 2 shows the evaluation performance of the filters for Vegetation area.

Table 2: Measurement Methods of the Various Filters for Speckle Noised in Vegetation Area image

Filter	Measurement Method						
	MSE	**AD**	**SI**	**PSNR**	**SNR**	**SSIM**	**ENL**
Frost	**71.19**	**9.62**	0.66	**19.45**	**5.35**	**0.64**	2.31
Lee	87.42	13.79	**0.54**	16.84	4.53	0.44	**3.46**
Median	79.68	10.62	0.72	18.66	4.86	0.53	1.91
Mean	74.97	10.51	0.65	18.83	5.12	0.54	2.36

*bold indicate better value/performance

The Table 2 shown, image filtered with Frost filter have 71.19 in MSE value and 9.62 in AD value or the lowest value than other filters. However, the lowest value of SI generated by Lee filters is 0.54. The low MSE, AD and SI value means to have better image quality. Image filtered with Frost filter has 19.45 in PSNR value, 5.35 in SNR value and 0.64 in SSIM value or the highest value than other filters. But for ENL highest value of 3.46 is produced by Lee filter. The high ENL, PSNR, SNR and SSIM value mean to have better image quality as described earlier.

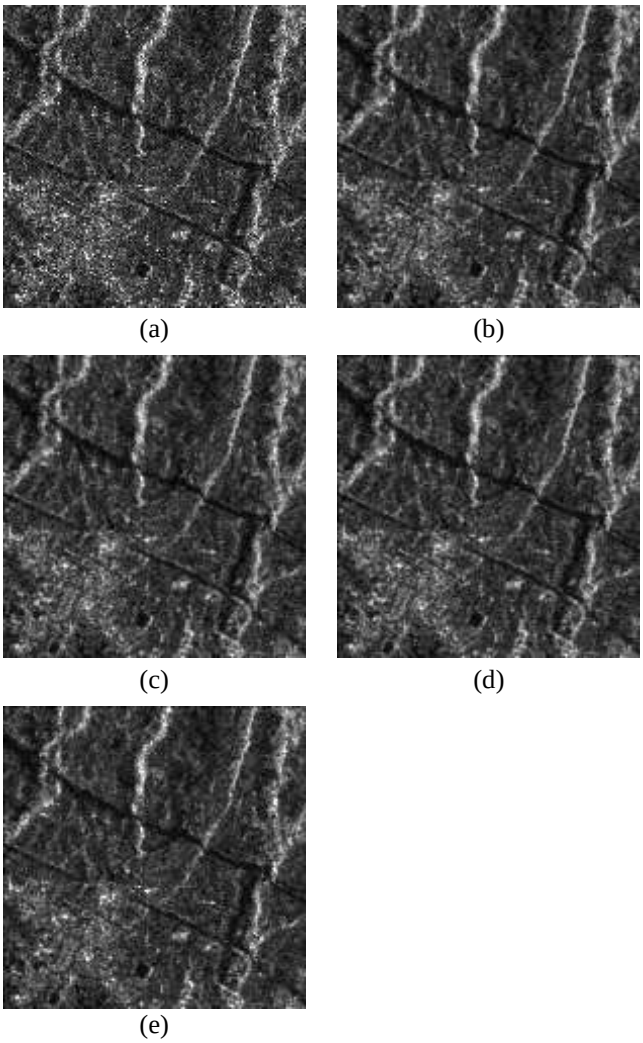


Figure 3: Filtered ALOS-PALSAR image of Hilly area by using various filter: (a) Original image, (b) Frost, (c) Lee, (d) Mean, (e) Median

Figure 3 shows the filtered image of Hilly Area by various filters. Figure 3.a represent the original image of Hilly area. Figure 3.b is the filtered image by Frost filter. Figure 3.c shows the filtered images by Lee filter. Figure 3.d is the filtered image by Mean filter and Figure 3.e shows the filtered image by Median filter. In addition, the performance of the filters is measured based on image quality parameters of the filtered images. The evaluation performance of the filters for Hilly area shows in Table 3.

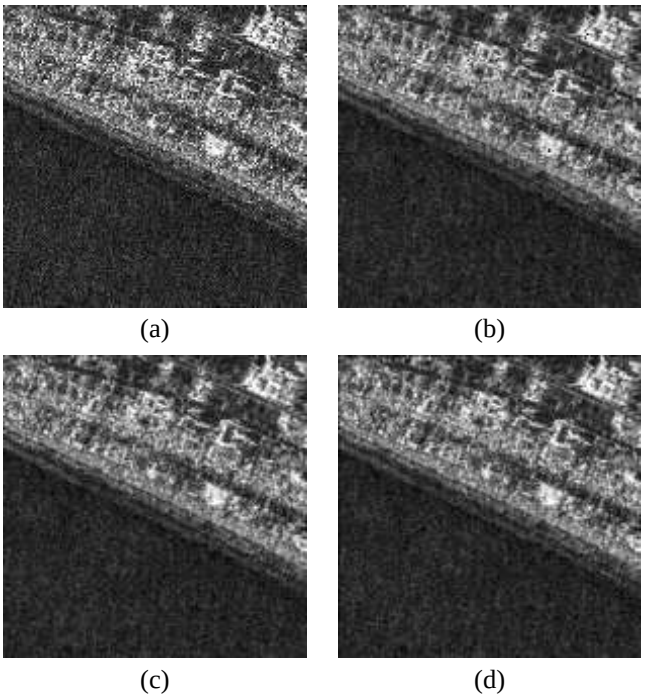
Table 3: Measurement Methods of the Various Filters for Speckle Noised in Hilly Area image

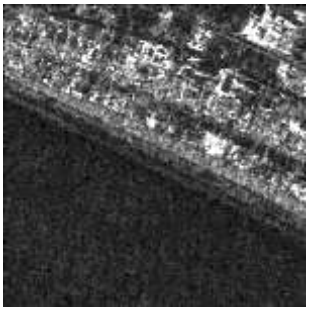
Filter	Measurement Method						
	MSE	**AD**	**SI**	**PSNR**	**SNR**	**SSIM**	**ENL**
Frost	**75.26**	**9.86**	0.50	**19.72**	**5.19**	**0.60**	4.03
Lee	77.95	10.82	**0.48**	18.82	5.03	0.50	**4.19**
Median	84.76	11.53	0.53	18.50	4.67	0.49	3.54
Mean	78.99	11.02	0.49	18.76	4.98	0.50	4.17

*bold indicate better value/performance

Table 3 shown, image filtered with Frost filter have 75.26 in MSE value and 9.86 in AD value or the lowest value than other filters. However, the lowest value of SI generated by Lee filters is 0.48. The low MSE, AD and SI value means to have better image quality. Image filtered with Frost filter has 19.72 in PSNR value, 5.19 in SNR value and 0.60 in SSIM value or the highest value than other filters. But for ENL highest value of 4.19 is produced by Lee filter. The high ENL, PSNR, SNR and SSIM value mean to have better image quality.

Figure 4 shows the filtered image of Sea Area by various filters. Figure 4.a represent the original image of Sea area. Figure 4.b is the filtered image by Frost filter.





(e)

Figure 4: Filtered ALOS-PALSAR image of Sea area by using various filter: (a) Original image, (b) Frost, (c) Lee, (d) Mean, (e) Median

Figure 4.c shows the filtered images by Lee filter. Figure 4.d is the filtered image by Mean filter and Figure 4.e shows the filtered image by Median filter. In these images, the performance of the filters also measured based on image quality parameters of the filtered images. Table 4 shows the evaluation performance of the filters for Sea area.

Table 4: Measurement Methods of the Various Filters for Speckle Noised in Sea Area image

Filter	**Measurement Method**						
	MSE	**AD**	**SI**	**PSNR**	**SNR**	**SSIM**	**ENL**
Frost	**76.91**	**10.55**	0.62	**18.80**	**5.13**	**0.57**	2.60
Lee	79.21	11.36	**0.61**	18.10	5.01	0.48	**2.66**
Median	80.45	10.99	0.68	17.99	4.94	0.49	2.19
Mean	80.25	11.56	0.62	18.06	4.95	0.48	2.64

*bold indicate better value/performance

Table 4 shown, image filtered with Frost filter have 76.91 in MSE value and 10.55 in AD value or the lowest value than other filters. However, the lowest value of SI generated by Lee filters of 0.61. The low MSE, AD and SI value means to have better image quality. Image filtered with Frost filter has 18.80 in PSNR value, 5.13 in SNR value and 0.57 in SSIM value or the highest value than other filters. But for ENL highest value of 2.66 is produced by Lee filter de-speckled image. The high ENL, PSNR, SNR and SSIM value mean to have better image quality.

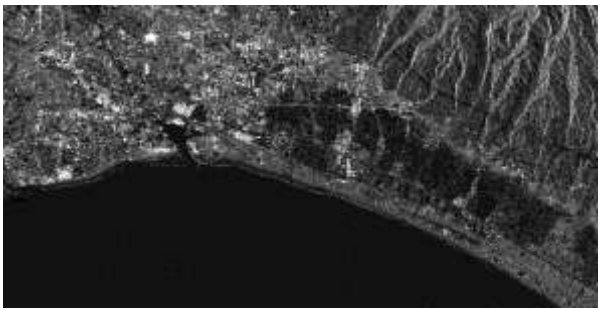
The next experiment was conducted as a comparison when the image consists of four types of areas, with an image size of 1225x2410 pixels.

(a)

(b)

(c)

(d)



(e)

Figure 5: Filtered ALOS-PALSAR image of Overall area by using various filter: (a) Original image, (b) Frost, (c) Lee, (d) Mean, (e) Median

Figure 5 shows the filtered image of Overall Area by various filters. Figure 5.a represent the original image of Overall area. Figure 5.b is the filtered image by Frost filter. Figure 5.c shows the filtered images by Lee filter. Figure 5.d is the filtered image by Mean filter and Figure 5.e shows the filtered image by Median filter. In addition, the performance of the filters is measured based on image quality parameters of the filtered images. The evaluation performance of the filters for Overall area shows in Table 5.

Table 5: Measurement Methods of the Various Filters for Speckle Noised in Overall Area image

Filter	Measurement Method						
	MSE	**AD**	**SI**	**PSNR**	**SNR**	**SSIM**	**ENL**
Frost	**62.56**	**8.54**	0.71	**20.13**	**5.84**	**0.99**	2.00
Lee	65.48	9.21	**0.69**	19.46	5.64	0.98	**2.04**
Median	64.55	9.54	0.75	19.41	5.70	0.97	1.78
Mean	65.55	9.24	0.70	19.45	5.63	0.98	2.04

*bold indicate better value/performance

The data in Table 5 shown, de-speckle image filtered with Frost filter have 62.56 in MSE value and 8.54 in AD value or the lowest value than other filters. However, the lowest value of SI generated by Lee filters de-speckled image of 0.69. The low MSE, AD and SI value means to have better image quality. Frost and Lee filter have the same behavior to produce the best metric parameters, such as on an experiment in four different areas. Frost filter produces the best metric value for MSE, AD, PSNR, SNR and SSIM. While Lee filter produces the best metric value for SI and ENL.

The data shown in Table 1,2,3,4 and 5, the best value of MSE and AD is 71.19 and 9.62 that provide in vegetation area image de-speckled by Frost filter. For the best value of SI is 0.48 generated by Lee filter in de-speckle Hilly area image. The best value of PSNR is 19.72 that provide in Hilly area image de-speckled by Frost filter. SNR value of 5.35 is the best that generated by Frost Filter in de-speckle Vegetation area image. The best SSIM value is 0.68 that provide in Urban area image de-speckled by Frost filter. And the best ENL value of 4.19 that provides in Hilly area image de-speckled by Lee filter.

The result measurement methods as shown in Table 1,2,3,4 and 5, shows that Frost filter performance slightly better than Lee filter. Frost's improve the ability of preserving the edges and texture compared to other filters. While Lee's ability is stronger in reducing speckle noise. The Median filter has lowest performance than other filters. This filter smooths the image for reducing speckle noise, but it causes the texture information eliminated during the filtering process. The Median's parameter value, it has been verified that this filter is unsuitable purposes for the ALOS-PALSAR images.

From the filters performance and by doing visual inspection of the despeckled images, it has been verified that the Frost filter is better than the other filters. Frost filter has better parameters values, which mean being able to produce good quality images than other filters. The frost filter produces an obvious example of speckle reduction and diffusion processing, and the features of tissues are enhanced. Frost presents a preserve the texture and sharpen the edge, and its filtering results are of the best visual appearance in our experiments than other filters. This represents an advantage of the frost filter, especially in ALOS-PALSAR's raw data which require clarity of the image for further processing.

CONCLUSION

The results show that the frost filters perform better than other filters. This filters applied in four typical areas of ALOS-PALSAR image, with windows size 3x3 filter. Frost filter mostly generates the best value for MSE, AD, PSNR, SNR and SSIM value than other filters in four different image areas. And the de-speckle image that filtered with Frost filter, shows sharpen edge and preserved texture. With this advantage, Frost Filter can use for ALOS-PALSAR data processing which requires clarity of the image.

FUTURE RESEARCH

This work can be further extended by using selected best filter for ALOS-PALSAR image in this experiment. Frost filters as the best selected filter will be enhanced with fuzzy algorithm. Then the proposed filter will be assessed and measured in term of the robustness into several SAR images with a different variety of objects on the earth surface.

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REFERENCES

[1] S. Foucher and C. Lopez-Martinez, "Analysis, evaluation, and comparison of polarimetric SAR speckle filtering techniques," IEEE Trans. Image Process., vol. 23, no. 4, pp. 1751–1764, Apr. 2014.

[2] R. Bamler, "Principles Of Synthetic Aperture Radar," Surv. Geophys., vol. 21, no. 2–3, pp. 147–157, 2000.

[3] S. Kuttikkad and R. Chellappa, "Statistical modeling and analysis of high-resolution Synthetic Aperture Radar images," Stat. Comput., vol. 10, no. 2, pp. 133–145, 2000.

[4] J. C. Curlander and R. N. McDonough, Synthetic Aperture Radar - Systems and Signal Processing. New York: Wiley-Interscience, 1991.

[5] Y. Dong, a. K. Milne, and B. C. Forster, "Toward edge sharpening: A SAR speckle filtering algorithm," IEEE Trans. Geosci. Remote Sens., vol. 39, no. 4, pp. 851–863, Apr. 2001.

[6] S. Wu, Q. Zhu, and Y. Xie, "Evaluation of various speckle reduction filters on medical ultrasound images.," in Proceedings of the 35th Annual International Conference of the IEEE Engineering in Medicine and Biology Society (EMBS), 2013, pp. 1148 – 1151.

[7] V. S. Frost, J. a Stiles, K. S. Shanmugan, and J. C. Holtzman, "A model for radar images and its application to adaptive digital filtering of multiplicative noise.," IEEE Trans. Pattern Anal. Mach. Intell., vol. 4, no. 2, pp. 157–166, Mar. 1982.

[8] R. Sivakumar, M. K. Gayathri, and D. Nedumaran, "Speckle filtering of ultrasound B-Scan Images - a comparative study between spatial and diffusion filters," in Proceedings of the IEEE Conference on Open Systems (ICOS), 2010, pp. 80–85.

[9] J. S. Lee, "Digital image enhancement and noise filtering by use of local statistics.," IEEE Trans. Pattern Anal. Mach. Intell., vol. 2, no. 2, pp. 165–168, Mar. 1980.

[10] J. Zhu, J. Wen, and Y. Zhang, "A new algorithm for SAR image despeckling using an enhanced Lee filter and median filter," in Proceedings of the 6th International

Congress on Image and Signal Processing (CISP), 2013, vol. 01, pp. 224–228.

[11] R. C. Gonzalez and R. E. Woods, Digital image processing, 2nd ed. New Jersey: Prentice Hall, 2002.

[12] N. Agrawal and K. Venugopalan, "Speckle reduction in remote sensing images," in Proceedings of the International Conference on Emerging Trends in Networks and Computer Communications (ETNCC), 2011, pp. 195–199.

[13] C. Oliver and S. Quegan, Understanding Synthetic Aperture Radar Images, vol. 42. SciTech Publ., 2004.

[14] D. Mata-Moya, P. Jarabo-Amores, J. M. Muñoz-Ferreras, J. M. De Nicolás-Presa Ángel, and P. Vázquez, "Speckle filtering for SAR imagery learning through heuristic method," in 2nd International Conference on Space Technology, ICST 2011, 2011, pp. 1–4.

[15] A. Maity, A. Pattanaik, S. Sagnika, and S. Pani, "A Comparative Study on Approaches to Speckle Noise Reduction in Images," in 2015 International Conference on Computational Intelligence and Networks, 2015, pp. 148–155.

[16] S. G. Dellepiane and E. Angiati, "Quality assessment of despeckled SAR images," IEEE J. Sel. Top. Appl. Earth Obs. Remote Sens., vol. 7, no. 2, pp. 691–707, 2014.

[17] F. N. S. Medeiros, N. D. a. Mascarenhas, and L. F. Costa, "Evaluation of speckle noise MAP filtering algorithms applied to SAR images," Int. J. Remote Sens., vol. 24, no. 24, pp. 5197–5218, Jan. 2003.

[18] A. M. Eskicioglu and P. S. Fisher, "Image quality measures and their performance," IEEE Trans. Commun., vol. 43, no. 12, pp. 2959–2965, 1995.

[19] W. Zhou and A. C. Bovik, "A universal image quality index," Signal Process. Lett. IEEE, vol. 9, no. 3, pp. 81–84, 2002.

[20] F. M. Henderson and J. L. Anthony, Principle and applications of imaging radar: Manual of Remote Sensing, 2nd ed. Somerset, New Jersey: John Wiley and Sons, Inc., 1998.

[21] Z. Wang, A. C. Bovik, H. R. Sheikh, and E. P. Simoncelli, "Image quality assessment: From error visibility to structural similarity," IEEE Trans. Image Process., vol. 13, no. 4, pp. 600–612, 2004.