

# Speckle Noise Reduction Method Based on Fuzzy Approach for Synthetic Aperture Radar Images

Ardhi Wicaksono Santoso\*, Luhur Bayuaji, Jasni Mohamad Zain  
Faculty of Computer System and Software Engineering  
University Malaysia Pahang  
Kuantan, Pahang, Malaysia  
ardhi.wicaksono@ymail.com\*

Ardhi Wicaksono Santoso  
Department of Electronics and Informatics, Vocational College  
Universitas Gadjah Mada  
Yogyakarta, Indonesia

Dwi Pebrianti  
Faculty of Electrical and Electronic Engineering  
University Malaysia Pahang  
Kuantan, Pahang, Malaysia

Lim Tien Sze  
Faculty of Engineering and Technology  
Multimedia University,  
Melaka, Malaysia

Habibah Lateh  
School of Distance Education  
University Sains Malaysia  
Penang, Malaysia

*Abstract*— Synthetic Aperture Radars (SAR) are classified as active sensors. It has been capable of producing images with high spatial resolution, and able to observe at day and night and in all-weather condition. With these advantages, SAR image becomes more popular than the Optical image. SAR image formation process led to speckle noise; it causes difficulties in the process of interpretation and analysis of SAR images. Fuzzy approach is a technique that can be used to reduce speckle noise. It has been used in the ultrasonic image in the medical field and showed good performance in image filtering to reduce speckle noise. Implemented to SAR images for reduce speckle noise by replacing the center pixel local neighbor Frost's with digital numbers that calculate by fuzzy filter. Proposed filters applied into a homogeneous and heterogeneous area in SAR images, aims to measure the robustness of the proposed filters in speckle noise reduction and texture preservation, mainly in homogeneous areas. All of areas is filtered using proposed filters; that's, Frost-TMED, Frost-ATMED, Frost-ATMAV and Frost-TMAV combination. Evaluation has been made, to measure the performance of filters, major in speckle noise reduction and texture preservation. The experiment result shows that the combination of Frost-TMAV has the highest performance. It has been verified that the Frost-TMAV filtering approach is performing better than the other filters, which mean being able to produce good-quality images than other filters. It also produces an obvious example of speckle reduction processing; features of tissues are enhanced and a good preserve on texture. The result shows that fuzzy approach has robustness to reduce speckle noise in SAR image, especially in ALOS-PALSAR's raw data, which require clarity of the image for further processing.

*Keywords*—synthetic aperture radar; speckle noise; filtering; fuzzy; remote-sensing

## 1. INTRODUCTION

One type of sensor for observation and characterization Earth's surface is Synthetic Aperture Radar (SAR) [1]. SAR sensor has several advantages such as, the ability to produce high spatial resolution images, observe in a day and night and in all-weather condition [2]. As it categorized as an active sensor, SAR sending electromagnetic waves toward the target surface and by coherently processing the returned backscattered signals from multiple distributed targets [3].

The SAR image suffers from two types of noise; first, the additive noises that come from the receiver thermal noise, and the second are multiplicative noise that mostly affected in images also known as speckle noise [2]. The speckle noise causes difficulties on interpretation, analyzing, detection and classification process of SAR image [4].

SAR Image must be free from noise to achieve a good analysis; therefore, the reduction of noise has become a commonly used routine pre-processing of SAR images [5]. One of the pre-processing techniques is by filtering speckle noise. The objective of using a speckle noise reduction filter is to smooth homogeneous regions while preserving texture information and edges. Various researchers have been conducted to reduce the speckle noise. Several methods have been proposed with their own strength and limitation [6].

In this study, we proposed and compare a filter which's a combination of the fuzzy algorithm [7] with qualified existing filter that applied to SAR image as describes in the previous study [8], aimed at eliminating speckle noise in. It also compared with original Frost filter [9], into ALOS-PALSAR image. The filters perform on 3x3 size of the moving window and applied into homogeneous and heterogeneous areas. And for evaluation of filter performance, several criteria such as, speckle noise reduction robustness, preservation of the mean and reduction of the standard deviation will be analyzed, used for comparative study.

## 2. SPECKLE NOISE REDUCTION

In this section, discussed speckle noise reduction techniques, which contains an explanation of speckle noise, speckle noise filtering, fuzzy approach to the reduction of speckle noise and frost filter as the most qualified classic filter.

### A. Speckle Noise

In this section, the speckle noise model is discussed before the fuzzy filters, the characteristics of the proposed filter and the comparative study explanation. Speckle noise in SAR images is generated during the process of creating the image with coherent radiation. This multiplicative noise as an undesired effect will degrade their quality [10]. SAR images also have statistical property, and most of these models evolved from a multiplicative model [11]. That is the noise varies more quickly in the regions those image gray changes faster, and the speckle is more serious in the brighter regions. It can be established as follows in (1).

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

where  $I(t)$  is the noise-affected signal and  $R(t)$  represent original image or the radar backscatter property without noise of ground targets, and the type of target determines the most appropriate distribution for each of the random variables,  $v(t)$  is speckle noise, and it is independent with  $R(t)$ . Because of SAR speckle, is generated by a zero-mean random phase of echo signals, the mean value of  $v(t)$  is one, and its variance is relevant with the equivalent number of SAR images [12].

With speckle noise in SAR image, it makes difficulties in detection and classification [4]. It must be eliminated as pre-processing SAR images. Speckle noise reduction is an important and essential procedure in most target detection and recognition systems. However, these techniques may cause loss of image details such us edge or texture information [10].

### B. Speckle Filtering

Filtering is a technique to remove unwanted information from an image, to make it more appropriate for the next step of the image-processing [5]. The main objective of Speckle filtering is removing noise in the uniform area, preserve texture and enhance the edge without changing features, and provide a good visual appearance. Speckle filtering works by moving a window over each pixel on the image. It moves over the image one pixel at a time until it fills the entire image. 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 [13].

Filtering techniques generally can be grouped into multilook processing and posterior speckle filtering techniques [14]. Multilook processing is applied during image formation, and this procedure averages several statistically independent looks of the same scene to reduce speckle [15]. A major disadvantage of this technique is that the resulting images suffer from a reduction in the

ground resolution that is proportional to the number of look's N [16]. To overcome this disadvantage, or to reduce speckle, many posterior speckle-filtering techniques have been developed. These techniques are based on either the spatial or the frequency domain.

### C. Fuzzy Filter

Compare with classical filter [7], Fuzzy filters provides better results in image-processing tasks. It copes with some drawbacks of classical filters. This filter is capable of dealing with unclear and uncertain information. Sometimes, it is required to recover a heavily noise corrupted images where a lot of uncertainties are present and in this case, fuzzy set theory is very useful. It uses each pixel in the image that represented by a membership function and different types of fuzzy rules that consider the neighborhood information or other information to eliminate noise [17]. Fuzzy filters are very robust in the sense that the classical filter removes the noise with blurry edges, but fuzzy filters perform both the edge preservation and smoothing [18]. Some fuzzy filters are mentioned below [7];

#### 1) Symmetrical triangle fuzzy filter with median center (TMED) Filter

According [17], the symmetrical triangular fuzzy filter with the median value within a window chosen as the center value expressed in (2).

$$F_{tmed}[x(i+r, j+s)] = \begin{cases} 1 - \frac{|x(i+r, j+s) - x_{med}(i, j)|}{x_{md}(i, j)}, & \text{for } |x(i+r, j+s) - x_{med}(i, j)| \leq x_{md}(i, j) \\ 1, & \text{for } x_{md} = 0 \end{cases} \quad (2)$$

where  $x_{md}(i, j)$  represent median value, calculate in (3).

$$x_{md}(i, j) = \max[x_{max}(i, j) - x_{med}(i, j), x_{med}(i, j) - x_{min}(i, j)] \quad (3)$$

$x_{max}(i, j)$ ,  $x_{min}(i, j)$  and  $x_{med}(i, j)$  are, respectively, the maximum value, the minimum value, and the median value of all the input values  $x(i+r, j+s)$  for  $r, r, s \in A$  within the window  $A$  at discrete indexes  $(i, j)$ .

#### 2) Asymmetrical triangle fuzzy filter with median center (ATMED) Filter

The asymmetrical triangular fuzzy filter with the median value within a window chosen as the center value expressed in (4).

$$F_{atmed}[x(i+r, j+s)] = \begin{cases} 1 - \frac{x(i+r, j+s) - x_{med}(i, j)}{x_{max}(i, j) - x_{med}(i, j)}, & \text{for } x_{med}(i, j) \leq x(i+r, j+s) \leq x_{max}(i, j) \\ 1 - \frac{x_{med}(i, j) - x(i+r, j+s)}{x_{med}(i, j) - x_{min}(i, j)}, & \text{for } x_{min}(i, j) \leq x(i+r, j+s) \leq x_{med}(i, j) \\ 1, & \text{for } x_{max}(i, j) - x_{med}(i, j) = 0 \text{ or } x_{med}(i, j) - x_{min}(i, j) = 0 \end{cases} \quad (4)$$

Unlike in (2), the triangle window function in (4) is asymmetrical. The degree of asymmetry depends of the difference between  $x_{med}(i, j) - x_{min}(i, j)$  and  $x_{max}(i, j) - x_{med}(i, j)$ .  $x_{max}(i, j)$ ,  $x_{min}(i, j)$  and  $x_{med}(i, j)$  are, respectively, the maximum value, the minimum value, and the median value of all the input values  $x(i+r, j+s)$  for  $r, r, s \in A$  within the window  $A$  at discrete indexes  $(i, j)$ .

#### 3) Symmetrical triangle fuzzy filter with moving average center (TMAV) Filter

The symmetrical triangular fuzzy filter with the moving average value within a window chosen as the center value expressed in (5).

$$F_{tmav}[x(i+r, j+s)] = \begin{cases} 1 - \frac{|x(i+r, j+s) - x_{mav}(i, j)|}{x_{mv}(i, j)}, & \text{for } |x(i+r, j+s) - x_{mav}(i, j)| \leq x_{mv}(i, j) \\ 1, & \text{for } x_{mv} = 0 \end{cases} \quad (5)$$

where  $x_{mv}(i, j)$  represent moving average value, calculate in (6).

$$x_{mv}(i, j) = \max[x_{max}(i, j) - x_{mav}(i, j), x_{mav}(i, j) - x_{min}(i, j)] \quad (6)$$

$x_{max}(i, j)$ ,  $x_{min}(i, j)$  and  $x_{mav}(i, j)$  are, respectively, the maximum value, the minimum value, and the moving average value of all the input values  $x(i + r, j + s)$  for  $r, r, s \in A$  within the window  $A$  at discrete indexes  $(i, j)$ .

#### 4) Asymmetrical triangle fuzzy filter with moving average center (ATMAV) Filter

The asymmetrical triangular fuzzy filter with the moving average value within a window chosen as the center value expressed in (7).

$$Fatmav[x(i + r, j + s)] = \begin{cases} 1 - \frac{x(i + r, j + s) - x_{mav}(i, j)}{x_{max}(i, j) - x_{mav}(i, j)}, & \text{for } x_{mav}(i, j) \leq x(i + r, j + s) \leq x_{max}(i, j) \\ 1 - \frac{x_{mav}(i, j) - x(i + r, j + s)}{x_{mav}(i, j) - x_{min}(i, j)}, & \text{for } x_{min}(i, j) \leq x(i + r, j + s) \leq x_{mav}(i, j) \\ 1, & \text{for } x_{max}(i, j) - x_{mav}(i, j) = 0 \text{ or } x_{mav}(i, j) - x_{min}(i, j) = 0 \end{cases} \quad (7)$$

The degree of asymmetry depends of the difference between  $x_{mav}(i, j) - x_{min}(i, j)$  and  $x_{max}(i, j) - x_{mav}(i, j)$ .  $x_{max}(i, j)$ ,  $x_{min}(i, j)$  and  $x_{mav}(i, j)$  are, respectively, the maximum value, the minimum value, and the moving average value of all the input values  $x(i + r, j + s)$  for  $r, r, s \in A$  within the window  $A$  at discrete indexes  $(i, j)$ .

#### D. Frost Filter

The Frost filter [9] 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. This means that at high coefficient variation, the filter attempts to preserve sharp features by retaining its original pixel value. At low coefficient variation, the filter is more average-like. This filter is described by mathematical expression in (8):

$$DN = \sum_{n \times n} k\alpha e^{-\alpha|t|} \quad (8)$$

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

### 3. PROPOSED FILTER

Frost filter as qualified filter that describes in the previous study [8], modified by combine with the fuzzy approach. As explained by [18], fuzzy has a good performance to reduce speckle noise in a medical image. Research on hybrid fuzzy filter conducted by [19], by combined sequentially wiener filter with fuzzy filter to speckle reduction in medical images. The purpose of the proposed method is to speckle noise reduction using a fuzzy approach, by combining the fuzzy filters with Frost filter. The architecture of proposed filter in this research as shown in Fig. 1.

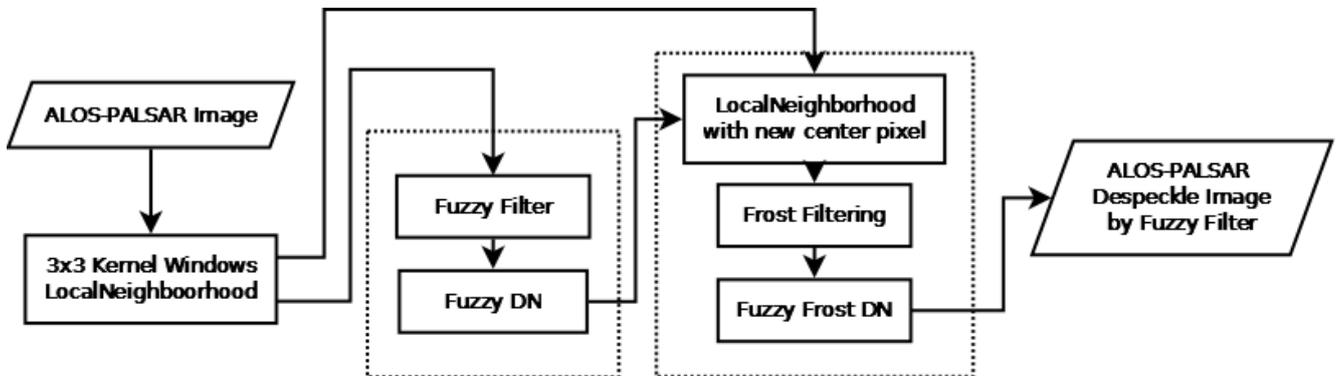


Figure 1: Architecture of proposed filter

Proposed Filter approach is to replace the center pixel local neighbor Frost's with digital numbers that calculate by fuzzy filter. This method assumes Frost filter's digital number calculation affected by mean value of local neighborhood. And by this combination, it proposes four fuzzy filters that will applied in SAR images.

Fourth proposed filters, applied in a homogeneous and heterogeneous area in SAR images, aims to measure the robustness of the fuzzy algorithm in speckle noise reduction and texture preservation, mainly in homogeneous areas. The results of these comparative studies, later will know the best combination of filter, which will be used for further work.

#### 4. RESULT AND DISCUSSION

In this section, we discuss the experimental results obtained by applying fourth proposed filters in SAR images. The data source for this study is grayscale SAR imagery with the type of ALOS-PALSAR located in Kuantan, Pahang, Malaysia.

##### A. Study Area and Implementation

The data taken is; First, three homogeneous areas with region area are Forests, Sea and Palm Oil Plantations, each 160 x 160 pixels in size, shown in Fig. 2 – Fig.4. Second, three heterogeneous areas, within the region contain Vegetation, Urban and River, each 420 x 420 pixels in size, shown in Fig. 5 – Fig.7.

All of areas is filtered using Proposed Filter; that's, Frost-TMED, Frost-ATMED, Frost-ATMAV and Frost-TMAV combination. 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 four parameters, major in speckle noise reduction and texture preservation.

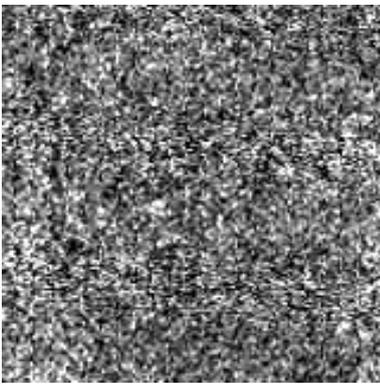


Figure 2: Forest Area

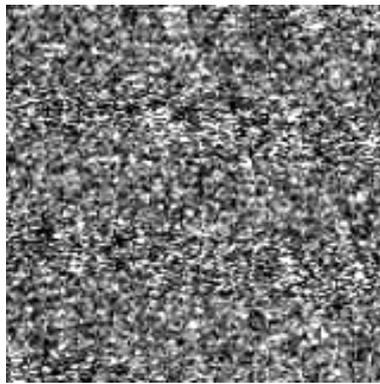


Figure 3: Sea Area

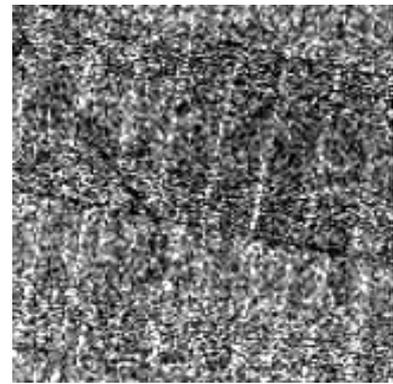


Figure 4: Palm Oil Plantation Area

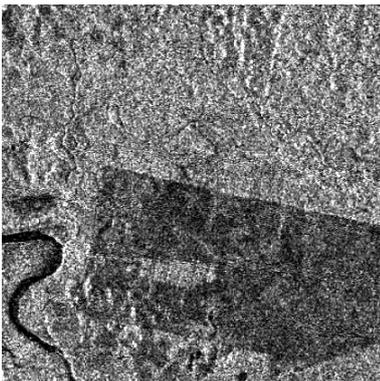


Figure 5: Vegetation Area

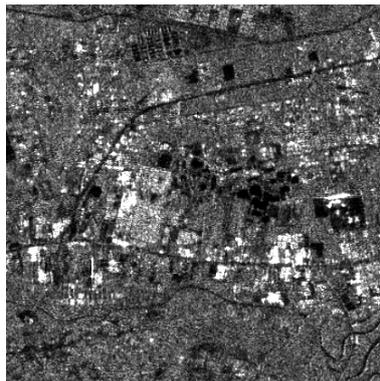


Figure 6: Urban Area



Figure 7: River Area

##### B. Performance Evaluation

In order to measure the performance of filter, four methods have been used. Those methods are Speckle Index (SI) [20]-[22] and Equivalent Number of Looks (ENL) [23], [24] for speckle noise reduction performance evaluation. According to [14], the equivalent number of looks (ENL) used to measure the degree of speckle reduction in an ALOS-PALSAR image. According to [25], ENL is often used to estimate the speckle noise level and is equivalent to the number of independent intensity values that are used per pixel and defined as (9).

$$ENL = \frac{mean(F)^2}{var(F)^2} \tag{9}$$

It is the ratio of mean to standard deviation and is a measure of the signal-to-noise ratio. The higher of ENL value, the stronger the speckle reduction.

Reference [13], used Speckle Index (SI) to evaluate speckle reduction in medical images. SI is a measure of speckle reduction in terms of average contrast in the image and expressed (10).

$$SI = \frac{1}{MN} \sum_{i=1}^M \sum_{j=1}^N \frac{\sigma(i,j)}{\mu(i,j)} \tag{10}$$

The  $\sigma(i,j)$  and  $\mu(i,j)$  are the standard deviation and means corresponding to a neighbor domain, respectively. Maximal value of SI corresponds to dissimilar image, and its minimal value corresponds to similar images or improved image quality.

According to [26], an important approach to region description is to quantify its texture content. The one principal approach used in order to describe the texture is by statistical. This is one of the simplest approaches for describing texture, by calculate the mean of grey level. Reference [14], using the standard deviation to measure the proximity of the image reconstruction approaches the original image, with lower value are better.

C. Experiment Result

There are four fuzzy filters that used in this study, namely; ATMED, ATMAV, TMED and TMAV. These filters will be combined with Frost filter to proposed Frost Fuzzy Filters. Thus proposed, namely; Frost-ATMED, Frost-ATMAV, Frost-TMED and Frost-TMAV. These filters will be applied in a homogeneous and heterogeneous area in SAR images. It aims to measure the robustness of the fuzzy algorithm in speckle noise reduction, and also texture preservation, mainly in homogeneous areas.

1) Homogeneous Area

Speckle Noise Reduction parameter data in Table 1, shows the highest ENL value achieved by the combination Frost-TMAV filter, it achieved in all difference areas, and this mean it has stronger ability to reduction the speckle noise. The lowest SI value also achieved by the combination Frost-TMAV filter as shown in Table 2, achieved in all difference areas, which mean the images contain little speckle noise because much reduction.

Table 1: ENL Value of Filters

Filter	Image Area		
	Forest	Sea	Plantation
Frost + ATMED	12.3875	12.1753	10.8499
Frost + ATMAV	13.0134	12.8251	11.2917
Frost + TMED	11.7158	12.0402	10.4279
Frost + TMAV	<u>13.7064</u>	<u>13.8659</u>	<u>11.8917</u>
Original Frost	11.521	11.2544	10.2302

underline indicate the highest/best value

Table 2: SI Value of Filters

Filter	Image Area		
	Forest	Sea	Plantation
Frost + ATMED	0.2841	0.2866	0.3036
Frost + ATMAV	0.2772	0.2792	0.2976
Frost + TMED	0.2922	0.2882	0.3097
Frost + TMAV	<u>0.2701</u>	<u>0.2686</u>	<u>0.2900</u>
Original Frost	0.2946	0.2981	0.3126

underline indicate the lowest/best value

The data in Table 1 shown, the highest ENL value achieved by the combination Frost-TMAV filter as represent in Fig.8, it achieved in all difference areas, and this mean it has stronger ability to reduction the speckle noise. The lowest SI value as represent in Fig. 9 also achieved by the combination Frost-TMAV filter, achieved in all difference areas, which mean the images contain little speckle noise because much reduction or better image quality.

ENL VALUE OF FILTERS

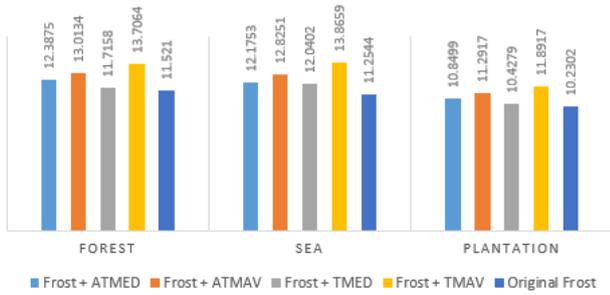


Figure 8: ENL Value of Filters Chart

SI VALUE OF FILTERS

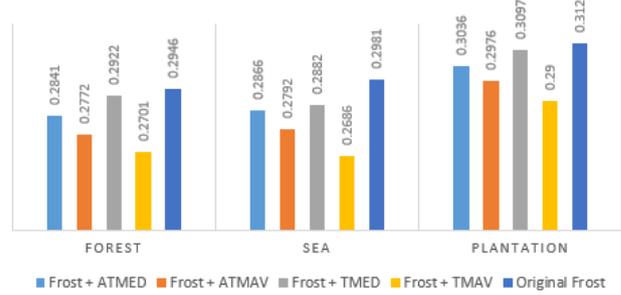


Figure 9: SI Value of Filters Chart

While the texture parameter data in Table 3, shown the highest mean of grey level value achieved by the combination Frost-TMED filter, it achieved in all difference areas as represent in Fig. 10.

Table 3: Mean Value of Filters

Filter	Image Area		
	Forest	Sea	Plantation
Frost + ATMED	114.2781	115.8707	112.9577
Frost + ATMAV	114.6532	116.2708	113.3697
Frost + TMED	<u>119.194</u>	<u>120.9464</u>	<u>118.4497</u>
Frost + TMAV	117.6676	119.3068	116.6829
Original Frost	114.7695	116.4918	113.5797

underline indicate the highest/best value

Table 4: Standard Deviation Value of Filters

Filter	Image Area		
	Forest	Sea	Plantation
Frost + ATMED	32.4691	33.2073	34.2929
Frost + ATMAV	<u>31.7827</u>	32.4668	<u>33.7378</u>
Frost + TMED	34.8231	34.8559	36.6804
Frost + TMAV	31.7831	<u>32.0398</u>	33.8364
Original Frost	33.8127	34.7244	35.5106

underline indicate the lowest/best value

Table 4 shows, the standard deviation value achieved by the combination Frost-ATMAV has better performance in forest and plantation area, but the combination Frost-TMAV has better performance in a sea area image as represent in Fig. 11.

MEAN VALUE OF FILTERS

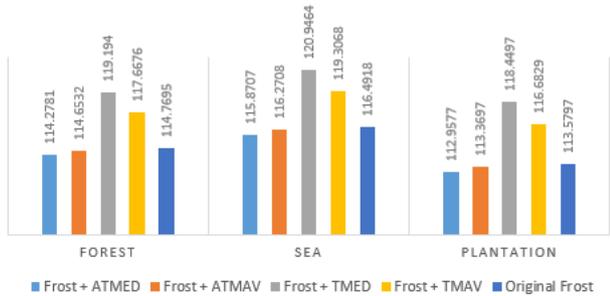


Figure 10: Mean Value of Filters Chart

STANDARD DEVIATION VALUE OF FILTERS



Figure 11: Standard Deviation Value of Filters Chart

From three different areas of images used in this study, the ENL value of sea areas is higher than forests and plantation areas. The texture of sea areas is relatively homogeneous. It has little differences in image pixel values, causes variance and standard deviation of images low values, while the mean of gray level is high. This also causes small in SI value as calculated in (10).

2) *Heterogeneous Area*

The heterogeneous area data, Speckle Noise Reduction parameter shown in Table 5. The highest ENL value achieved by the combination Frost-TMAV filter, it achieved in all difference areas. This combination also has the lowest SI value as shown in Table 6, it achieved in vegetation and urban areas, while in river areas, Frost+TMED combination slightly better than other filters.

Table 5: ENL Value of Filters

Filter	Image Area		
	Vegetation	Urban	River
Frost + ATMED	10.8951	5.0838	2.2382
Frost + ATMAV	11.3752	5.2369	2.2648
Frost + TMED	10.6873	5.4131	2.2674
Frost + TMAV	<u>12.0751</u>	<u>5.4663</u>	<u>2.2790</u>
Original Frost	10.2908	4.8861	2.1960

underline indicate the highest/best value

Table 6: SI Value of Filters

Filter	Image Area		
	Vegetation	Urban	River
Frost + ATMED	0.3030	0.4435	0.6498
Frost + ATMAV	0.2965	0.4370	0.6433
Frost + TMED	0.3059	0.4298	<u>0.6116</u>
Frost + TMAV	<u>0.2878</u>	<u>0.4277</u>	0.6210
Original Frost	0.3117	0.4524	0.6533

underline indicate the lowest/best value

The result of ENL and SI value that achieved by the combination Frost-TMAV filters as represent in Fig. 12 and Fig. 13, indicate that the filtered images, less in speckle noise because much reduction. The highest ENL value indicate it has stronger ability to reduction the speckle noise. The lowest SI value, it mean the images contain little speckle noise because much reduction or better image quality.

ENL VALUE OF FILTERS

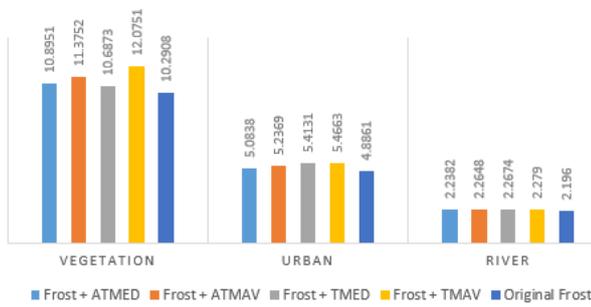


Figure 12: ENL of Filters Chart

SI VALUE OF FILTERS

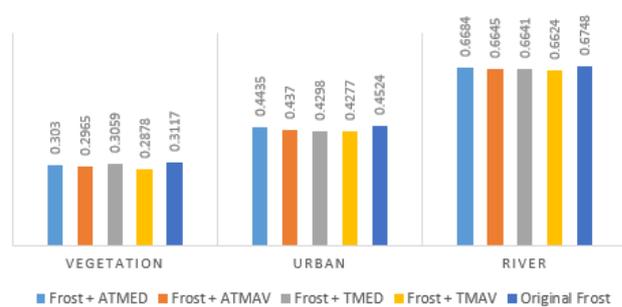


Figure 13: SI Value of Filters Chart

Table 7, shown the highest mean of grey level value achieved by the combination Frost-TMED filter, it achieved in all difference areas as represent in Fig. 14.

Table 7: Mean Value of Filters

Filter	Image Area		
	Vegetation	Urban	River
Frost + ATMED	114.3705	85.928	71.9712
Frost + ATMAV	114.7729	86.2918	72.2269
Frost + TMED	<u>119.6295</u>	<u>91.3263</u>	<u>76.0648</u>
Frost + TMAV	117.9424	89.7573	74.9212
Original Frost	114.9801	86.7563	72.6868

underline indicate the highest/best value

Table 8: Standard Deviation Value of Filters

Filter	Image Area		
	Vegetation	Urban	River
Frost + ATMED	34.6496	38.1101	48.1072
Frost + ATMAV	34.0298	<u>37.7078</u>	<u>47.9942</u>
Frost + TMED	36.5936	39.2531	50.5152
Frost + TMAV	<u>33.941</u>	38.3904	49.6281
Original Frost	35.8425	39.2481	49.0502

underline indicate the lowest/best value

MEAN VALUE OF FILTERS

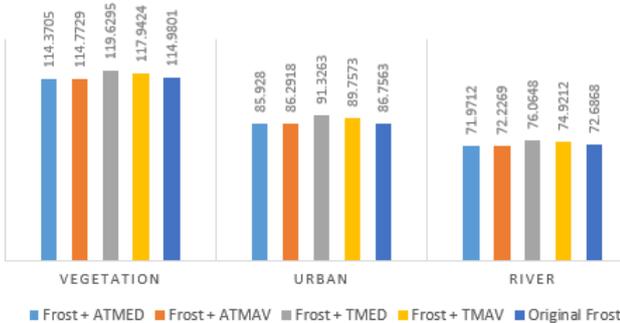


Figure 14: Mean Value of Filters Chart

STANDARD DEVIATION VALUE OF FILTERS

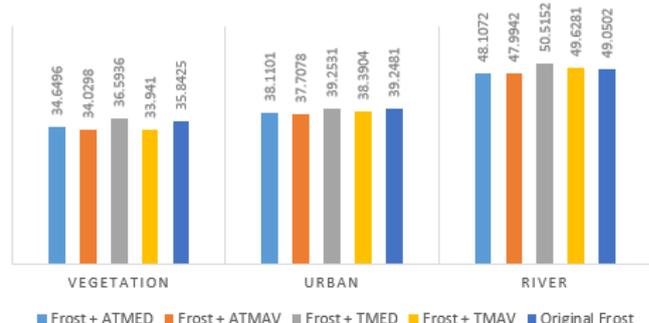


Figure 15: Standard Deviation Value of Filters Chart

Table 8 shows the Standard deviation value that achieved by the combination Frost-ATMAV has better performance in urban and river area, but the combination Frost-TMAV has better performance in a vegetation area image as represent in Fig. 15.

From three different images of Heterogeneous areas used, vegetation area as represent in Fig. 6, has the most homogeneous region compare to urban and river areas. It makes pixel values of the images have small standard deviation and variance value, but high in the mean of gray level value, causes highest ENL and smallest SI value.

The experiment result shows that the combination of Frost-TMAV has the highest performance. It has been verified that the Frost-TMAV filtering approach is performing better than the other filters, which mean being able to produce good-quality images than other filters. It also produces an obvious example of speckle reduction processing, features of tissues are enhanced and a good preserve on texture.

The result shows that fuzzy approach has robustness to reduce speckle noise in SAR image, especially in ALOS-PALSAR's raw data, which require clarity of the image for further processing.

## 5. CONCLUSION

The result shows that Fuzzy approach have robustness to reduce speckle noise in SAR image, by the combination Frost-TMAV, perform better performance than other filters. This filters applied in each three Homogeneous and Heterogeneous areas of ALOS-PALSAR image, with windows size 3x3 filter. Frost-TMAV filter mostly generates the best value for ENL, SI and Standard Deviation value than other filters. And the de-speckle image that filtered with Frost filter, shows better in speckle noise reduction and good preserve on texture. With this advantage, Frost-TMAV filter can use for ALOS-PALSAR data processing which requires clarity of the image.

## ACKNOWLEDGMENT

The authors gratefully acknowledge for the support from Fundamental Research Grant Scheme (RDU130114), UMP-PRGS (GRS150318) and Research Acculturation Collaborative Effort (RDU141311), awarded to Universiti Malaysia Pahang by Ministry of Higher Education Malaysia.

## 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, 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] 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.
- [6] 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.
- [7] H. K. Kwan and Y. Cai, "Fuzzy filters for image filtering," in *Proceedings of the 45th Midwest Symposium on Circuits and Systems (MWSCAS)*, 2002, vol. 3, pp. III–672–675.
- [8] A. W. Santoso, D. Pebrianti, L. Bayuaji, and J. M. Zain, "Performance of various speckle reduction filters on Synthetic Aperture Radar image," in *Proceedings of the 4th International Conference on Software Engineering and Computer Systems (ICSECS)*, 2015, pp. 11–14.
- [9] 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.
- [10] 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.
- [11] 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.
- [12] 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.
- [13] 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.
- [14] J. T. S. Sumantyo and J. Amini, "A model for removal of speckle noise in SAR images (ALOS PALSAR)," *Can. J. Remote Sens.*, vol. 34, no. 6, pp. 503–516, 2008.
- [15] L. J. Porcello, N. G. Massey, R. B. Innes, and J. M. Marks, "Speckle reduction in synthetic radars," *Journal of the Optical Society of America*, vol. 66, pp. 1305–1311, 1976.
- [16] F. J. Martin and R. W. Turner, "SAR speckle reduction by weighted filtering," *International Journal of Remote Sensing*, vol. 14, pp. 1759–1774, 1993.

- [17] H. K. Kwan, "Fuzzy filters for noisy image filtering," in Proceedings of the 2003 International Symposium on Circuits and Systems, 2003. ISCAS '03., 2003, vol. 4, pp. IV-161-IV-164.
- [18] D. S. Rao, M. Seetha, and M. H. M. K. Prasad, "Quality Assessment Parameters for Iterative Image Fusion Using Fuzzy and Neuro Fuzzy Logic and Applications," *Procedia Technol.*, vol. 19, pp. 888-894, 2015.
- [19] N. Biradar, M. L. Dewal, and M. Rohit, "Speckle Noise Reduction using Hybrid TMAV based Fuzzy Filter," *Int. J. Res. Eng. Technol.*, vol. 3, no. 3, pp. 113-118, 2014.
- [20] 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.
- [21] A. M. Eskicioglu and P. S. Fisher, "Image quality measures and their performance," *IEEE Trans. Commun.*, vol. 43, no. 12, pp. 2959-2965, 1995.
- [22] Z. Wang and A. C. Bovik, "A universal image quality index," *IEEE Signal Process. Lett.*, vol. 9, no. 3, pp. 81-84, 2002.
- [23] C. Oliver and S. Quegan, *Understanding Synthetic Aperture Radar Images*, vol. 42. SciTech Publ., 2004.
- [24] F. M. Henderson and J. L. Anthony, *Wiley: Manual of Remote Sensing, Volume 2, Principles and Applications of Imaging Radar*, 3rd Edition. Somerset, New Jersey: John Wiley and Sons, Inc., 1998.
- [25] L. Gagnon and A. Jouan, "Speckle Filtering of SAR Images - A Comparative Study Between Complex-Wavelet-Based and Standard Filters," in Proceedings of SPIE, 1997, vol. 3169, pp. 80-91.
- [26] R. C. Gonzalez and R. E. Woods, *Digital image processing*, 2nd ed. New Jersey: Prentice Hall, 2002.