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A fuzzy approach for speckle noise reduction in SAR images

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A B S T R A C T

The Synthetic Aperture Radar (SAR) image has a high resolution and not influenced by weather conditions either day or night. SAR image with its advantages, is becoming popular than the optical image in earth observation using the remote-sensing techniques. However, the speckle noise that occurs in the SAR image causes difficulties in image interpretation. Thus, speckle noise reduction needs as prepossessing procedure prior to the use of the SAR images. The ideal speckle filter has the capability of reducing speckle noise without losing the information and preserving texture. Fuzzy approach has a good performance to reduce speckle noise in a medical image, which is occurred on a SAR image. It proposed a filter which is a combination of fuzzy with qualified existing filter that applied to SAR image, aimed at eliminating speckle noise while maintaining texture. The results showed that the proposed filter has better performance than commonly used filters such as the Mean, Median, Kuan, Lee, and Frost filters. The experiments conducted in a homogeneous area; forests, plantations and oceans from ALOS-PALSAR image in the area of Kuantan, Pahang, Malaysia.

1. Introduction

Geographical information can indicate natural resources and spatial phenomena on earth. Geographical Information Systems (GIS) is an implementation of information technology in the field of geography, that collecting, structuring, processing and analysis of spatial data to obtain spatial information to solve problems on Earth (Kennedy, 2009). Chandra et al. (2006) describes, Remote Sensing (RS) is one of the technologies used to collect GIS spatial data. According to Lillesand et al. (2004), RS is a science to obtain and analyze information about the object or phenomenon from a distance, by detects the characteristics of the electromagnetic radiation reflected/emitted by the earth's surface.

Based on the sensors used to produce images, RS systems can be divided into two, passive sensors that produce optical images and active sensors that produce radar imagery. Optical imaging system (passive sensors) requires day lighting while imaging radar (active sensor) using an active lighting system. In the process of image formation, the antenna mounted in an aircraft or spacecraft transmits the radar signals in the side view in the direction of the earth's surface. (ESA, 2004)

Synthetic Aperture Radar (SAR) is a type of sensor used for observation and characterization of Earth's surface (Foucher and Lopez-Martinez, 2014). SAR sensor has several advantages such as the ability to produce high spatial resolution images, capable to observe in day and night and all-weather condition (Bamler, 2000). SAR is categorized as an active sensor. As an active sensor, SAR sends electromagnetic waves towards the target surface and coherently processes the returned back scattered signals from multiple distributed targets (Kuttikkad et al., 2000).

Unfortunately, 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. The speckle noise causes difficulties on interpretation and analyzing process of SAR image (Bamler, 2000). Speckle noise in SAR images will degrade their quality, and this is an undesired effect. This multiplicative noise is

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generated during the process of creating the image with coherent radiation (Mata-Moya et al., 2011). SAR images also have statistical property, and most of the statistical models evolved from multiplicative noise model.

Therefore, speckle reduction has become an important pre-processing step in (SAR) image before doing other advanced process. The objective of using a speckle reduction filter is to smooth out the homogeneous regions while preserving texture information and edges. Various researchers have been conducted to reduce the speckle (despeckling). Several methods have been proposed with their own strength and limitation (Dong et al., 2001).

According to Kumar and Srinivasan (2013), Fuzzy approach has a good performance to reduce speckle noise in a medical image, which is occurred on a SAR image. Aim of this study is to investigate fuzzy based algorithms to reduce speckle in SAR image, to measure the ability of fuzzy on reducing the speckle noise in SAR image and compared against the existing algorithm (Zhu et al., 2013).

In this study, we proposed a filter which is a combination of the fuzzy algorithm with qualified existing filter that applied to SAR image as describes in the previous study (Santoso et al., 2015), aimed at eliminating speckle noise while maintaining texture. Proposed filter compared with most commonly used filters for speckle reduction, namely Lee filter (Lee, 1980), Frost filter (Frost et al., 1982), Kuan filter (Kuan et al., 1985), Mean and Median filter (Gonzalez and Woods, 2002), into ALOS-PALSAR image. The filters perform on 3x3 size of the moving window and applied into several homogeneous areas. The evaluation of filter performance includes several criteria such as, speckle noise reduction robustness, preservation of the mean, reduction of the standard deviation, and texture preservation.

2. Material and method

2.1. Speckle noise

The speckle noise model is discussed before a detailed discussion about the characteristics of the proposed filter and the comparison with other filters. Speckle noise in SAR images will degrade their quality, and this is an undesired effect. This multiplicative noise is generated during the process of creating the image with coherent radiation (Mata-Moya et al, 2011). According to Zhu et al (2013), SAR images also have statistical property, and most of the statistical models evolved from a multiplicative model. 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. SAR image speckle is fully developed, so it can be established as follows in Eq. 1:

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

Where *I(t)* is the noise-affected signal and *R(t)* represent the original image, *v(t)* is speckle noise.

2.2. 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 (Maity et al., 2015). 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 (Wu et al., 2013).

2.3. Proposed fuzzy filter

Frost filter as qualified filter that describes in the previous study (Santoso et al., 2015); modified by combine with the fuzzy approach. The Frost filter (Frost et al., 1982) 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 Eq. 2.

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

where a 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.

Fuzzy approach as explained by Kumar and Srinivasan (2013), has a good performance to reduce speckle noise in a medical image. Nagashettappa et al. (2014), conduct research on hybrid fuzzy filter, by combined sequentially wiener filter with fuzzy filter to speckle reduction in medical images. The medical images filtered by fuzzy filter and then results are filtered using the wiener filter. He also conducts the logarithmic operation to convert multiplicative noise into addictive noise, and also exponential operation to the opposite.

Proposed Filter approach is to replace the center pixel local neighbor Frost's with digital numbers that calculate by TMAV filter. This method assumes Frost filter's digital number calculation affected by mean value of local neighbor, whereas TMAV calculates mean value based on the fuzzy degree of membership local neighborhood as presented in Eqs. 3 and 4 (Kwan, 2003).

$$F[f(i+r,j+s)] = \quad (3)$$
$$f_{mv}(i,j) = \quad (4)$$

The maximum $f_{max}(i,j)$, minimum $f_{min}(i,j)$ and moving average values are $f_{mav}(i,j)$, with $s, r \in A$, the window at indices *(i,j)*. The output of the fuzzy TMAV filter are estimated using Eq. 5 given below:

$$y(i,j) = \frac{\sum_{(r,s)\in A} F[f(i+r,j+s)].f(i+r,j+s)}{\sum_{(r,s)\in A} F[f(i+r,j+s)]} \quad (5)$$

where $[f(i,j)]$ and A are the window function and area respectively. Furthermore, in this research the performance of the proposed method is expressed in terms of four performance parameters, major in speckle noise reduction and texture preservation.

The purpose of the proposed method is to speckle noise reduction using a fuzzy approach, by combining one of the fuzzy filters, the symmetrical triangular fuzzy filter with moving average center (TMAV) with Frost filter and the architecture of proposed filter in this research as shown in Fig. 1.

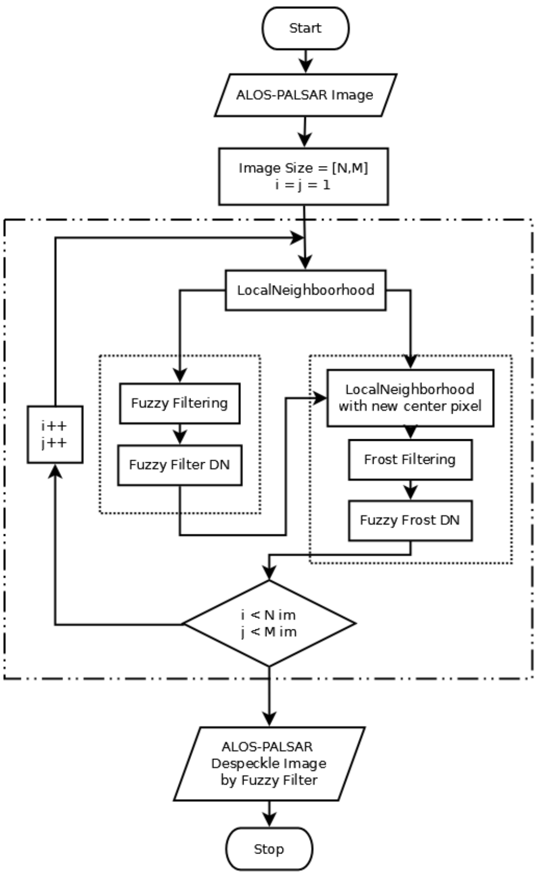

Fig. 1: Architecture of proposed filter

3. Result and discussion

3.1. Study area and implementation

The data source for this research is the SAR imagery with the type of ALOS-PALSAR. Images are gray scale images; the data taken is three homogeneous fields in Kuantan, Pahang, Malaysia. The region is an area of forests, sea and oil palm plantations, with 160x160 pixels size for each type of area, each shown in Fig. 2, 3 and 4 below.

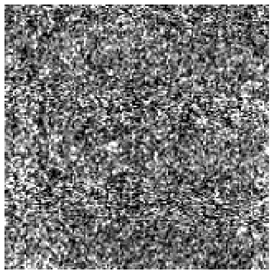
Fig. 2: Forest area

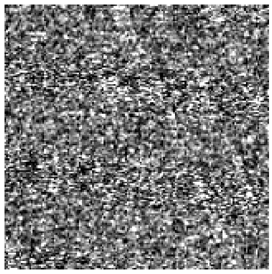
Fig. 3: Sea area

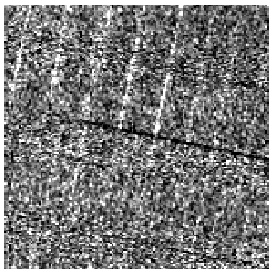
Fig. 4: Oil palm plantation area

These three different homogeneous areas filtered using Proposed Filter, Lee, Frost, Kuan, Mean and Median Filter, by using 3x3 windows sized. 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.

3.2. Image quality evaluation

Sumantyo and Amini (2008), use the equivalent number of looks (ENL) to measure the degree of speckle reduction in an ALOS-PALSAR image. According to Gagnon and Jouan (1997), 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 in over a homogeneous area is defined as Eq. 6.

$$ENL = \frac{mean\ (F)^2}{var\ (F)^2} \quad (6)$$

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.

Wu et al (2013), 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 in Eq. 7.

$$SI = \frac{1}{MN}\sum_{i=1}^{M}\sum_{j=1}^{N}\frac{\sigma(i,j)}{\mu(i,j)} \quad (7)$$

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.

Sumantyo and Amini (2008), also use second-order texture, namely variance to measure the retention of texture information in the original and filtered images.

Fig. 5 shows the ENL value of various filters. Compared with other filters, proposed filter shows the highest performance for speckle noise reduction, based on highest ENL value. Despeckle image filtered with proposed filter have 13.7064 in forest area, 13.8659 in sea area and 13.2782 in oil palm area. This highest ENL value indicates that proposed filter has stronger ability to reduction the speckle noise.

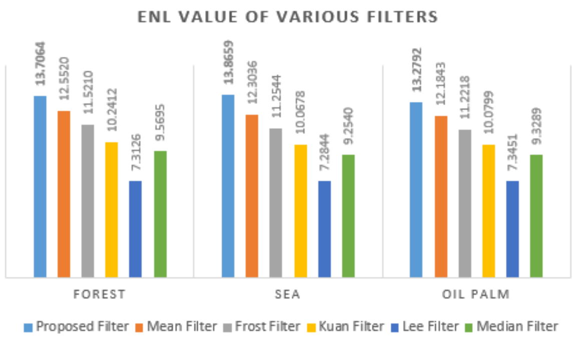

Fig. 5: ENL value of various filters

The SI value of various filters shows in Fig. 6. Proposed filter's despeckle images has 0.2701 in forest area, 0.2686 in sea area and 0.2744 in oil palm area for SI values. The lowest value of SI indicate the images contain little speckle noise because much reduction.

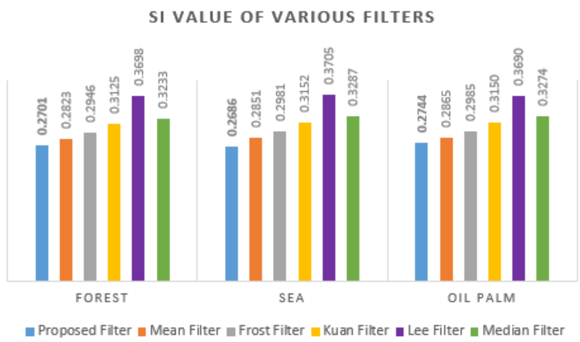

Fig. 6: SI value of various filters

According to Gonzalez and Woods (2002), 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. Statistical approach is one of the simplest approaches for describing texture; by calculate the mean of grey level. Sumantyo and Amini (2008), using the standard deviation to measure the proximity of the image reconstruction approaches the original image, with lower value is better.

The Mean value of various filters represents in Fig. 7, shows that proposed filters have highest value compared with other filters. The mean value of Proposed filter despeckle images has 117.6676 in forest area, 119.3068 in sea area and 116.9883 in oil palm area. The highest value of mean indicates the highest level of intensity of the image or texture.

The standard deviation value of various filters and represent by Fig. 8. The lowest standard deviation value achieved by Proposed filter despeckle images has 31.7831 in forest area, 32.0398 in sea area and 32.1038 oil palm area.

The variance value of various filters and represent by Fig. 9. Proposed filter's despeckle images has 1010.20 in forest area, 1026.60 in sea area and 1144.90 in oil palm area for variance values. The lowest value of variance describes the variation of intensity around the mean, this indicate the homogeneity of texture area is more preserved.

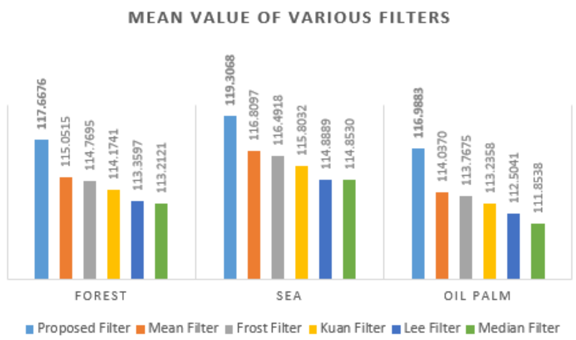

Fig. 7: Mean value of various filters

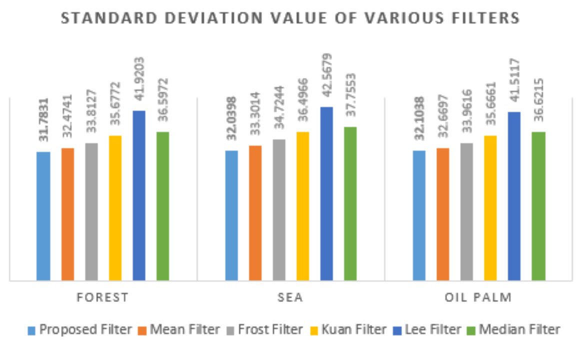

Fig. 8: Standard deviation value of various filters

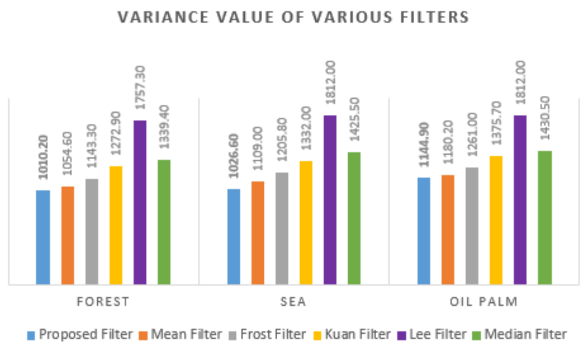

Fig. 9: Variance value of various filters

By applied into three difference homogeneous areas in Kuantan ALOS-PALSAR images, proposed filter in comparison with other filters, shows the highest performance for texture parameter measurement, based on the highest mean value, lowest Standard Deviation value and lowest variance value measured.

From the performance evaluation of speckle noise reduction and texture measurement applied filters into homogeneous areas in Kuantan ALOS-PALSAR images, it has been verified that the Proposed Filter is performing better than the other filters. Proposed filter has better parameter's values, which means being able to produce good-quality images than other filters. This represents an advantage of the proposed filter, especially in ALOS-PALSAR images, which require clarity of the image for further processing.

4. Conclusion

The results show that the proposed filters perform better than other filters. These filters applied in three differences homogeneous areas in Kuantan ALOS-PALSAR images; with windows size 3x3 filters. Proposed filter shows the robustness in speckle noise reduction and also in the highest texture measurement parameter which means good texture preserved. This advantage makes Proposed Filter can use for ALOS-PALSAR data processing, which requires clarity of the image.

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