Analisa filter spekler single dan multitemporal data Sentinel 1-A

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Abstract. Speckle is noise found in SAR data that will affect the image interpretation process. To reduce the presence of speckle in SAR data, a speckle filtering process is needed. This study will evaluate the multi temporal speckle filtering for Sentinel-1 image, VH polarisation. The data used in this study are 30 SENTINEL-1 images recorded in different seasons in 2018. The methods applied for multi temporal speckle filters are Boxcar, Frost, Lee, Gamma Map and Lee Sigma with window sizes of 5x5 and 7x7. The quality test for speckle filter results will be done qualitatively (by looking at the visual appearance of the filter results) and quantitatively (Mean Square Error (MSE), Peak Signal to Noise Ratio (PSNR) and Normalized Mean (NM). The best qualitative and quantitative multitemporal speckle filter results are obtained from the Frost Filter 5x5 with a minimum of 3 scene data.

1. Introduction
Sentinel-1 is a satellite developed by the European Space Agency (ESA) since 2014. This satellite carries the C-band Shyntetic Aperture Radar instrument. The radar sensor on the satellite emits electromagnetic waves and the waves will be reflected back by objects on the surface of the earth to the sensors. Due to the different roughness of each object, when the object reflects back electromagnetic waves, it can cause elementary scattering mechanism (surface scattering, double-bounce scattering, volume scattering, helix scattering). Wave signals reflected from some elementary scatterers can experience coherent interference, this can cause the appearance of spots (speckle noise) on SAR image Lee and Pottier [1]. The presence of speckle noise causes a decrease in the radiometric quality of SAR images and will cause difficulties in visual interpretation [2-4]. Speckle noise can be minimized by doing the speckle filtering process or commonly called despeckling. The despeckling process is a key factor that aims to capture target characteristics such as edges, textures and shapes by smoothing the speckle noise pattern [2]. SNAP (Sentinel Application Platform) software is an open source software developed by Brockmann Consult Array Systems Computing and C-S. SNAP can be used to process and analyze SAR data. The speckle filter technique in SNAP is available in two option including speckle filter using single data and multitemporal data. The research on speckle filtering method using multitemporal data is still carry out infrequently by users, because of the single data filter method is more preferable [5-8]. The advantage of single speckle filtering is that it does not require a lot of data, whereas in multitemporal speckle filters require more than 1 scene data so that it requires a computer with memory and greater data storage capacity. Nevertheless, multitemporal speckle filtering have advantages in terms of the quality of the data produced. Multitemporal speckle filtering produced data with better spatial detail and significantly reduced speckle noise [9].

Sentinel-1 data can be used for SAR data study continuously and free of charge. Data acquisition that carried out once every 12 days at the same location, leading Sentinel-1 data easy to obtain, so the multi temporal speckle filter process can be easily carried out. If properly stacked SAR data are available, it is recommended for time series data stacks to be preprocessed with multitemporal speckle filter [10].
This paper aims to evaluate several multitemporal SAR speckle filter methods in SNAP software and the results will be evaluated qualitatively and quantitatively.

2. Method

The speckle filter method in the SNAP software consists of scalar (Median) and adaptive techniques (Boxcar, Frost, Gamma Map, Lee, Lee Sigma and Refined Lee). In this study speckle filtering evaluation will be conducted on adaptive filters including: Boxcar, Frost, Gamma Map, Lee and Lee Sigma. Quantitative speckle filter performance test results will be performed using the Mean Square Error (MSE), Peak Signal to Noise Ratio (PSNR) and Normalized Mean (NM) methods.

2.1. Speckle Noise Filter

The different speckle filter approaches that have been considered are following:

2.1.1. Boxcar Filter

Filter Boxcar [11] performs the sample mean over pixel neighbourhood within a sliding window of \((N_w \times N_w)\) pixels. Filtered intensity estimates described by (1) below.

\[
\hat{X}_{i,j} = \langle Y_{i,j} \rangle_{N_w} = \frac{1}{N_w^2} \sum_{p=-N_w/2}^{N_w/2} \sum_{q=-N_w/2}^{N_w/2} Y_{i+p,j+q}
\]

Where:

\(\hat{X}\) = Filtered intensity estimates
\(\langle Y \rangle\) = Sample mean of a speckle intensity
\(N_w\) = Number of sliding window pixels
\(i\) = Pixel row index
\(j\) = Column row index

This mean approach on Boxcar filtering present the best performance over homogeneous area. But in the heterogeneous area, this filter generally make sharp edges blur and point scatters are transform into spread targets.

2.1.2. Frost Filter

Frost filter [12] is made adaptive to smoothing radar images by using locally estimated parameter values that is perform Minimum Mean Square Error (MMSE) estimates inside homogeneous area while preserving the edge structure. This filter algorithm enhances the utility of radar images for target discrimination, geologic analysis, and agricultural assessment. Filter frost provides a better performance in homogeneous area because it can maintain the small spatial extent of the point targets.

2.1.3. Gamma Map Filter

The focus on the MAP filter [13] is to produces a constant pixel estimation value in homogeneous class such as agriculture area while it does not eliminate information on targets, edges, and target points in heterogeneous classes such as forests. Gamma MAP filter assumes that the original pixel value is between the pixel of interest value and the average of moving pixel kernel. In the vegetation area (homogeneous class), the gamma map filter performs better. This approach uses variation coefficient and contrast ratio. This filter is better than Frost Filter [14], but both filters will blur the edges [15].

2.1.4. Lee Filter

Lee filter [16] is developed for additive and multiplicative noise case based on their local mean and variance. The algorithm is a linear weighted sum of the local mean and the image. It applies the Minimum Mean-Square Estimator to obtain the noise filtering. The characteristic of this filter is it’s performed better in low local variances. Otherwise in high contrast area or in high local variance areas, such as it retains the edge information.
2.1.5. Lee Sigma Filter

Lee sigma [17] uses sigma probability of the Gaussian distribution so that it smooths the noise by observe the intensities within a fixed sigma range of the center pixel and then averaging only the neighbourhood pixels. Lee sigma uses two condition that described in (2):

\[
\hat{x}_{i,j} = \begin{cases} 
two - \text{sigma average}, & \text{if } M > K 
immediate \text{neighbor average}, & \text{if } M \leq K 
\end{cases}
\]

Where:

\[ x_{i,j} = \text{The intensity or grey level of pixel } i,j \]
\[ M = \text{The number of pixels within the intensity range} \]
\[ K = \text{The prespecified value} \]

By two condition, Lee Sigma has the characteristics of smoothing the area near the edge without making blur because only pixels on the one side are averaged. In addition, these filters also maintain linear features such as roads of 1 to 3 pixels in width because only the intensity around the edges is done by the average process.

2.2. Quality Assessment of the Filtered Images

In order to evaluate performance of speckle noise filtering method, there are some parameters that can be used as follow [18].

2.2.1. MSE (Mean Square Error)

MSE is the measure of the extent to which the output image differs from the input image. This method is using statistic parameter to detects the difference between the filtered \( (I') \) and the original image \( (I) \). The formula is written as below.

\[
MSE = \frac{1}{MN} \sum_{x=1}^{M} \sum_{y=1}^{N} (I(x,y) - I'(x,y))^2
\]

Where:

\[ M \times N = \text{size of images} \]
\[ x, y = \text{row and column location of pixel position in the image} \]

Indicator: If MSE parameter is having low value, it means the filter method is having good result in noise reduction.

2.2.2. PSNR (Peak Signal to Noise Ratio)

The ability of filters to improve image quality is generally assessed using parameters namely Peak Signal to Noise Ratio (PSNR). PSNR is defined from MSE. It measures image quality by using the following equation:

\[
PSNR = 10 \log_{10} \left( \frac{255^2}{MSE} \right)
\]

Where:

Value 255 is referring to gray level for 8 bit of the given image
MSE is referring to Mean Square Error

Indicator: If PSNR parameter is having high value, it means the filter is having better performance to improve image quality.

PSNR is more commonly used than the MSE, because people tend to associate the quality of an image with a certain range of PSNR. Below table is illustrate the relationship between PSNR value with quality image [19].
2.2.3. NM (Normalized Mean)
Normalized Mean is one of parameter to show that a used filter method is still successful in maintaining image information. Practically, this parameter is criterion to evaluate whether the filter give unbiased estimation or not. The formula is written as below:

\[
\frac{M_{\text{filtered}}}{M_{\text{original}}}
\]

Where: \( M_{\text{filtered}} \) and \( M_{\text{original}} \) denote the mean value of pre-filter and post-filter for the same image

Indicator: If the NM value approaches 1, it shows that the estimation is unbiased, which illuminates that the filtering method saves good original image information [20].

2.3. Data Processing
The steps of data processing used in this research is depicted in Figure 1 [21]:

![Figure 1. Data processing flowchart](image)

The multitemporal speckle filter will using the window size of 5x5 and 7x7.

3. Result and discussion
This research is focused on the mainland area with the southern Subang Regency study area. Its coordinates are 6°18'29" - 6°45'07" S and 107°35'42" - 108°0'54" E. The data used is Sentinel 1A, VV and VH polarization Ground Range Data (GRD), recording between January 3 and December 2, 2018 (30 scene data).

For a simple quantitative evaluation of the filters, standard deviations value is used. The results of the single speckle filter study showed that image quality was getting better when the standard deviation value is on the smallest possible value [6, 22, 23]. Standard deviation is used to see how close the pixel value is to the Mean value. If the standard deviation value is close to zero, it means that the image quality is getting better because the pixel value distribution is getting closer to the Mean value.

In this study it appears that the standard deviation value has decreased from when in state of raw data (subset of data 0) to the data that has been processed by the filter speckle (subset of data 1), while the increase in the standard deviation occurs in the subset 2 of data and will slowly decrease after adding data from a subset of 3 data up to a subset of 30 data (Figure 2). Although when using 3 data subsets up to using 30 data subsets the standard deviation value is decreasing, the decrement value was not too significant. In Figure 2, it can be seen that the standard deviation value has fallen monotonously to the 0.02 value.
The incremental standard deviation value turned out to have a visual effect on the multitemporal speckle filtering processed data in the form of appearing objects in sharper images (Figure 3). Raw data (Figure 3a) appears to contain noise, after a speckle filter is performed on a single image that produces blurred images (Figure 3b). After multitemporal speckle filtering 2 data, objects in the image will appear clear but still contain patches (Figure 3c). The appearance of the image becomes clearer and the effect of the speckle is reduced after a speckle filter process is carried out with a stack of more than 2 data (Figure 3d, e, f).

![Figure 2. Standard deviation raw and filter image](image)

The result of the quantitative test by calculating MSE, PSNR dan NM toward 30 Sentinel data with VV, VH polarization is depicted in the Table1 and Table2 below.

![Table 1 and Table2](image)
Table 1. Mean Square Error (MSE) VV Polarization

| Filter Method & window size | Number of data |
|---------------------------|----------------|
|                           | 1  | 2   | 3   | 4   | 5   | 6   | 7   | 8   | 9   | 10  | 20  | 30  |
| Boxcar 5x5                | 2.812 | 1.598 | 1.790 | 1.898 | 1.957 | 2.005 | 2.035 | 2.061 | 2.081 | 2.097 | 2.097 | 2.212 |
| Frost 5x5                 | 2.437 | 1.417 | 1.586 | 1.680 | 1.732 | 1.773 | 1.799 | 1.822 | 1.839 | 1.853 | 1.853 | 1.952 |
| Gamma Map 5x5             | 2.757 | 1.585 | 1.775 | 1.882 | 1.942 | 1.989 | 2.020 | 2.046 | 2.066 | 2.082 | 2.082 | 2.195 |
| Lee 5X5                   | 2.774 | 1.584 | 1.775 | 1.882 | 1.941 | 1.989 | 2.019 | 2.045 | 2.064 | 2.080 | 2.080 | 2.194 |
| Lee Sigma 5x5             | 2.530 | 1.492 | 1.670 | 1.768 | 1.823 | 1.866 | 1.894 | 1.917 | 1.935 | 1.950 | 1.950 | 2.052 |
| Boxcar 7x7                | 4.107 | 2.185 | 2.458 | 2.613 | 2.698 | 2.768 | 2.811 | 2.850 | 2.880 | 2.904 | 2.904 | 3.079 |
| Frost 7x7                 | 3.299 | 1.844 | 2.069 | 2.195 | 2.265 | 2.321 | 2.357 | 2.387 | 2.411 | 2.430 | 2.430 | 2.568 |
| Gamma Map 7x7             | 3.985 | 2.163 | 2.432 | 2.585 | 2.670 | 2.740 | 2.784 | 2.823 | 2.853 | 2.877 | 2.877 | 3.046 |
| Lee 7x7                   | 4.020 | 2.157 | 2.427 | 2.580 | 2.665 | 2.733 | 2.777 | 2.815 | 2.845 | 2.869 | 2.869 | 3.040 |
| Lee Sigma 7x7             | 3.388 | 1.929 | 2.165 | 2.297 | 2.370 | 2.428 | 2.465 | 2.497 | 2.522 | 2.542 | 2.542 | 2.684 |

Table 2. Mean Square Error (MSE) VH Polarization

| Filter Method & window size | Number of data |
|---------------------------|----------------|
|                           | 1  | 2   | 3   | 4   | 5   | 6   | 7   | 8   | 9   | 10  | 20  | 30  |
| Boxcar 5x5                | 2.560 | 1.563 | 1.748 | 1.832 | 1.888 | 1.932 | 1.960 | 1.985 | 2.001 | 2.015 | 2.079 | 2.109 |
| Frost 5x5                 | 2.291 | 1.412 | 1.580 | 1.656 | 1.707 | 1.746 | 1.772 | 1.794 | 1.808 | 1.820 | 1.878 | 1.904 |
| Gamma Map 5x5             | 2.471 | 1.581 | 1.715 | 1.796 | 1.851 | 1.893 | 1.922 | 1.946 | 1.962 | 1.976 | 2.037 | 2.066 |
| Lee 5X5                   | 2.497 | 1.538 | 1.720 | 1.801 | 1.857 | 1.899 | 1.927 | 1.951 | 1.967 | 1.981 | 2.043 | 2.072 |
| Lee Sigma 5x5             | 2.394 | 1.486 | 1.663 | 1.743 | 1.796 | 1.836 | 1.863 | 1.886 | 1.900 | 1.913 | 1.974 | 2.001 |
| Boxcar 7x7                | 3.672 | 2.121 | 2.380 | 2.494 | 2.575 | 2.637 | 2.680 | 2.717 | 2.742 | 2.762 | 2.853 | 2.901 |
| Frost 7x7                 | 3.096 | 1.834 | 2.057 | 2.156 | 2.225 | 2.278 | 2.313 | 2.343 | 2.363 | 2.380 | 2.458 | 2.496 |
| Gamma Map 7x7             | 3.490 | 2.070 | 2.320 | 2.430 | 2.508 | 2.568 | 2.609 | 2.645 | 2.669 | 2.689 | 2.777 | 2.822 |
| Lee 7x7                   | 3.537 | 2.073 | 2.324 | 2.435 | 2.512 | 2.573 | 2.614 | 2.650 | 2.674 | 2.694 | 2.782 | 2.827 |
| Lee Sigma 7x7             | 3.194 | 1.923 | 2.154 | 2.258 | 2.328 | 2.382 | 2.418 | 2.449 | 2.470 | 2.488 | 2.568 | 2.608 |

From the MSE calculation, the VV and VH polarization gave the best results on the Frost Filter 5x5 (Table 1 and Table 2). Small MSE value shows that the filter is able to reducing the noise. Based on the MSE values it shows that the Frost 5x5 filter results are able to maintain objects in the image that has not been filtered. In the multitemporal speckle filter VV and VH polarization, the smallest MSE is when 2 data are stacked.

Likewise, the PSNR values of VV and VH polarization gave the best results on the Frost Filter 5x5 filter (Tables 3 and Table 4). High PSNR shows good filter capabilities in improving image quality. The highest PSNR values in the VV and VH polarizations are found in stack of 2 data.

Table 3. Peak Signal to Noise Ratio (PSNR) VV Polarization

| Filter Method & Kernel size | Number of data |
|---------------------------|----------------|
|                           | 1  | 2   | 3   | 4   | 5   | 6   | 7   | 8   | 9   | 10  | 20  | 30  |
| Boxcar 5x5                | 35.51 | 37.966 | 37.472 | 37.217 | 37.084 | 36.979 | 36.915 | 36.859 | 36.818 | 36.628 | 36.628 | 36.553 |
| Frost 5x5                 | 36.132 | 38.486 | 37.996 | 37.746 | 37.615 | 37.513 | 37.449 | 37.395 | 37.354 | 37.168 | 37.168 | 37.096 |
The best NM values are VV and VH. In addition to calculating the ability of the filter to reduce noise (MSE) and the ability of the filter to maintain image information using NM parameters, from the NM results, the best results on the VV and VH polarization were found in the Frost 5x5 filter (Table 5 and Table 6). The best NM values are VV polarization and VH is in stack of 2 data.

| Filter Method & window size | Number of data | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 20 | 30 |
|----------------------------|----------------|----|----|----|----|----|----|----|----|----|-----|-----|-----|
| Boxcar 5x5                 | 36.026         | 36.130 | 36.646 | 36.444 | 37.313 | 37.216 | 37.152 | 37.097 | 37.062 | 37.032 | 36.898 | 36.836 |
| Frost 5x5                  | 36.208         | 36.279 | 37.792 | 37.588 | 37.457 | 37.361 | 37.298 | 37.246 | 37.211 | 37.182 | 37.048 | 36.988 |
| Gamma Map 5x5              | 34.351         | 36.735 | 36.235 | 36.030 | 35.893 | 35.788 | 35.719 | 35.659 | 35.620 | 35.588 | 35.447 | 35.375 |
| Lee Sigma 5x5              | 34.513         | 36.833 | 36.338 | 36.135 | 35.999 | 35.896 | 35.828 | 35.768 | 35.729 | 35.696 | 35.557 | 35.486 |
| Lee Sigma 7x7              | 34.956         | 36.161 | 36.667 | 36.463 | 36.330 | 36.230 | 36.165 | 36.109 | 36.073 | 36.042 | 35.903 | 35.838 |

Table 5. Normalized Mean (NM) VV Polarization

In addition to calculating the ability of the filter to reduce noise (MSE) and the ability of the filter to improve the quality of the PSNR image, it is necessary to calculate the ability of the filter to maintain image information using NM parameters. From the NM results, the best results on the VV and VH polarization were found in the Frost 5x5 filter (Table 5 and Table 6). The best NM values are VV polarization and VH is in stack of 2 data.
In this study, the best results of the quantitative test were obtained when 2 data are stacked, but if the result of stacking 2 data is visually viewed (Figure 3c) the image still looks blotchy. Whereas on the stack of 3 data (Figure 3d), the image looks softer, so the best results are obtained with a stack of at least 3 data.

To compare the results of multispectral speckle filtering visually, some samples of paddy fields were taken. From the processing results, the Frost 5x5 filter gives the best results, where it is able to display paddy fields (showed by blue arrow in Figure 5c) more clearly than other methods where the object appears blurry. Frost is the best filter method that produces high complexity and best performance (preserve high contrast edges and other objects) [22].

Table 6. Normalized Mean (NM) VH Polarization

| Filter Method & window size | Number of data |
|----------------------------|----------------|
|                            | 1  | 2  | 3  | 4  | 5  | 6  | 7  | 8  | 9  | 10 | 20 | 30 |
| Boxcar 5x5                 | 1.02515 | 1.00973 | 1.01125 | 1.01217 | 1.01277 | 1.01321 | 1.01338 | 1.01352 | 1.01368 | 1.01374 | 1.01423 | 1.01442 |
| Frost 5x5                  | 1.02362 | 1.00892 | 1.01028 | 1.01110 | 1.01163 | 1.01203 | 1.01219 | 1.01251 | 1.01246 | 1.01251 | 1.01295 | 1.01311 |
| Gamma Map 5x5              | 1.02387 | 1.00926 | 1.01073 | 1.01165 | 1.01227 | 1.01274 | 1.01294 | 1.01311 | 1.01329 | 1.01337 | 1.01383 | 1.01397 |
| Lee 5x5                    | 1.02454 | 1.00945 | 1.01094 | 1.01186 | 1.01246 | 1.01291 | 1.01309 | 1.01324 | 1.01340 | 1.01347 | 1.01394 | 1.01411 |
| Lee Sigma 5x5              | 1.02439 | 1.00948 | 1.01087 | 1.01172 | 1.01226 | 1.01266 | 1.01283 | 1.01296 | 1.01311 | 1.01317 | 1.01362 | 1.01379 |
| Boxcar 7x7                 | 1.03102 | 1.01320 | 1.01531 | 1.01661 | 1.01745 | 1.01810 | 1.01837 | 1.01858 | 1.01882 | 1.01892 | 1.01964 | 1.01992 |
| Frost 7x7                  | 1.02820 | 1.01160 | 1.01337 | 1.01447 | 1.01519 | 1.01573 | 1.01597 | 1.01615 | 1.01643 | 1.01704 | 1.01726 |
| Gamma Map 7x7              | 1.02884 | 1.01243 | 1.01443 | 1.01572 | 1.01659 | 1.01725 | 1.01755 | 1.01781 | 1.01808 | 1.01820 | 1.01886 | 1.01908 |
| Lee 7x7                    | 1.03005 | 1.01272 | 1.01477 | 1.01605 | 1.01689 | 1.01754 | 1.01781 | 1.01803 | 1.01828 | 1.01838 | 1.01907 | 1.01933 |
| Lee Sigma 7x7              | 1.02777 | 1.01236 | 1.01415 | 1.01526 | 1.01595 | 1.01647 | 1.01671 | 1.01690 | 1.01711 | 1.01720 | 1.01781 | 1.01805 |
Figure 4. Result of the multitemporal speckle filtering with 5x5 kernel: (a) Boxcar, (c) Frost, (e) Gamma Map, (g) Lee, (i) Lee Sigma; Kernel 7x7: (b) Boxcar, (d) Frost, (f) Gamma Map, (h) Lee, (j) Lee Sigma

4. Conclusion
Multitemporal speckle filtering is one of the methods used to improve image quality. From the results of qualitative and quantitative test, it is concluded that the Frost 5x5 filter with a stacking of at least 3 data, is the best multitemporal speckle filtering method.

Based on quantitative tests this method produces the smallest MSE value which shows that the filter results have a minimum difference with the image before filtering so that the filter is able to maintain the object. Frost 5x5 filter also has the highest PSNR value which means it can improve image quality. In addition, its NM values is close to 1, which means it can maintain information in the filtered images. Based on qualitative testing, the Frost 5x5 filter method is able to maintain high contrast edges. Increasing the amount of data to the multitemporal speckle process can improve data quality visually.

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