Speckle noise reduction of Sentinel-1 SAR data using fast fourier transform temporal filtering to monitor paddy field area

Kustiyo¹, Rokhmatuloh¹, A H Saputro¹, and D Kushardono²
¹ University of Indonesia, Kampus UI Depok 16424, Jakarta, Indonesia
² National Institute of Aeronautics and Space (LAPAN), Jakarta 13710, Indonesia
E-mail: kuslapan@yahoo.com

Abstract. Synthetic Aperture Radar (SAR) images have the ability to work in any weather situation. It is mostly impossible to get cloud free optical image monthly in Indonesia, especially in Subang. So, the use of SAR imagery for the monthly monitoring of paddy is recommended. The disadvantage of the SAR images is noise, known as speckle noise. This noise reduces the quality of the image; reducing the speckle noise is necessary. This research proposes the FFT algorithm to remove the speckle noise. Because the frequency pattern of FFT is periodic, and the research focuses on the paddy field area, so the one year of paddy growth was used. There are many planting times in the research area, from one to three planting times a year; most of the area is twice planting time a year. Six scenarios of the FFT filter were proposed and investigated to select the optimum scenario. The scenarios use the number of FFT results to implement in filtering. The first scenario used FFT1 to FFT2, and the sixth scenario used FFT-1 to FFT-8. The performance results were measure by the correlation value of the original image and the results of FFT filtering. The results show that by increasing the number of FFT in the filtering process, the correlation increase. The minimal FFT filtering is FFT1-FFT3 filtering, with the average correlation is 87%, but some acquisition still has the correlation less than 85%. The optimum is FFT1-FFT5 filtering, with the average correlation, is 92%, and all correlations are above 85% for all data during a year. Using the optimum scenario, the backscattered trend of paddy growth could be identified better and easier, so this technique is recommended for paddy growth monitoring.

1. Introduction
High cloud cover in equatorial region such as Indonesia cause the providing cloud free optical remote sensing data is difficult. This research is using Synthetic Aperture Radar (SAR) data that can penetrate the haze and cloud, but it contains of speckle noise, so it has to be reduced. The noise reduction can be done using spatial domain or frequency domain filtering techniques [1]. The spatial domain can be used box filter, median filter or local statistic filter [2]. The most research in noise reduction of SAR image using are spatial domain, such as Lee filtering [3], using combine Lee and median filter [4], using Local Adaptive Median Filter [5] and using Gaussian Markov Random Field [6]. The used of frequency domain is limited, such as using iterative threshold of wavelet [7]. Oher researcher focus on preserve edge image [8], and focus on pasture area [9].

On the other hand, several research in FFT area estimation have been done, FFT is used in any applications including earth and science, chemistry, communications, and signal processing [10]. FFT process need huge capacity so design processing is needed to make faster processing [11]. FFT can be done using continues FFT or discrete FFT [12], and fixed-point fast or integer FFT [13].
This research proposes the noise reduction algorithm using FFT of temporal data. One-year period of sentinel-1 was used corresponding with the period of paddy growth cycle. The optimum result was selected by comparing the six scenarios of FFT filtering using correlation value of the original image and the results of FFT filtering. Hope, this research can be implemented to whole are of Indonesia to monitor paddy field.

2. Methods

2.1. Study area

Research study area is Subang District, West Java province. Geographically, Subang is located between 107° 31' - 107° 54' East and 6° 11' - 6° 49' South. The topographic is various, from 0 meter in the beach to 1500 meter above sea level in the mountain, the annual rainfall is about 2352 mm/year and 100 rain days a year, so this region was dominated by agriculture especially for paddy. Subang support rice production as the third largest rice production in West Java, about 41.21 percent of the total area is paddy field. The figure 1 shows the research area of Subang.

![Figure 1. Study area](image)

2.2. Data

| Item            | Description               |
|-----------------|---------------------------|
| Satellite name  | Sentinel-1                |
| Wave length     | C band                    |
| Mode            | IW (Interferometric wide swath) |
| Resolution      | 10x10 meter               |
| Product level   | Product: GRD              |
| Polarization    | VH, and VV                |
| Ascending/Descending | Descending             |

This research used whole Sentinel-1 data were acquired from October 2019 to September 2020, there are 31 data. Each single acquisition data was pre-processed in Google Erath Engine (GEE) and downloaded. The Sentinel-1 is the European Radar Observatory for Copernicus joint initiative of the European Commission and the European Space Agency (ESA). The mission is composed of a constellation of two satellites, Sentinel-1A and Sentinel-1B, sharing the same orbital plane. It equipped with the C-SAR instrument, can offer reliable and repeated wide area monitoring [14]. The Sentinel-1 data specification was described in Table 1. The level 1 data of Multi-Look Ground Range Detected (GRD) was used. GRD product is projected to ground range using an Earth ellipsoid model corrected with specified terrain height which maintains the original satellite path direction and includes complete georeferencing information. The result has nearly square spatial resolution and square pixel spacing.
with reduced speckle. Multi-looking is a processing property that results in images with reduced speckle, but also with reduced resolution: the more looks the less speckle noise and the lower the resolution.

Table 2 describe the list of acquisition date that was used in this research, it used one-year cycle period of paddy growth. The number of full acquisitions is 31 data, but some data is missing. Total data is 23 acquisitions.

| Month          | Date-1     | Date-2     | Date-3     |
|---------------|------------|------------|------------|
| October 2019  | 2019-10-01 | 2019-10-13 | 2019-10-25 |
| November 2019 | 2019-11-06 | 2019-11-18 | 2019-11-30 |
| December 2019 | 2019-12-12 | 2019-12-24*|            |
| January 2020  | 2020-01-05 | 2020-01-17 | 2020-01-29 |
| February 2020 | 2020-02-10 | 2020-02-22*|            |
| March 2020    | 2020-03-05 | 2020-03-17*| 2020-03-29*|
| April 2020    | 2020-04-10*| 2020-04-22 |            |
| May 2020      | 2020-05-04*| 2020-05-16*| 2020-05-28 |
| June 2020     | 2020-06-09 | 2020-06-21 |            |
| July 2020     | 2020-07-03 | 2020-07-15 | 2020-07-27 |
| August 2020   | 2020-08-08 | 2020-08-20 |            |
| September 2020| 2020-09-01 | 2020-09-13*| 2020-09-25 |

*no-data (missing data)

The processing flow was shown in figure 2. The pre-processing was done on-line using GEE. The results were downloaded and then processed off-line. The missing data were interpolated using previous and after acquisition date. The all 31 data in a year period was transform to the frequency domain using temporal FFT, the results are FFT1 to FFT31. Then the FFT1 to FFT-n, was selected and transform back using IFFT (Invers FFT) with the rest FFT were set to zero. The results of IFFT is backscattered in time domain, this result is filtered images. Six scenarios of FFT filtering were investigated to select the optimum scenario. First scenario used FFT1-FFT2, and the sixth scenario used FFT-1 to FFT-8. The performance results were measure by correlation value of the original image and the results of FFT filtering.

2.3. Pre-processing
The input data from GRD Sentinel-1 collection from GEE is already in sigma0 backscatter. Additional processing was applied, first is transformation from Sigma0 to Gamma0, and flattened to correct the topographic effect. The final pixel resolution was saved to 20x20 meter. The Gab-filling was applied to fill the no-data caused by no acquisition data and layover during topographic flatterning process. The linier interpolation technique was used in the gab-filling process.

2.4. FFT
Fourier Transform is introduced by Jean Baptiste Joseph Fourier to solve the computational complexity in wide varieties of fields such as earth and science. FFT convert signal in time domain to frequency domain [10]. FFT is a basic approach to remote sensing image processing, it applied to process hyperspectral, high spatial resolution and high temporal resolution. FFT algorithm can be used for stripe noise removal, image compression, image registration. [11]
2.5. Comparison and analysis
To assets to FFT results, the analysis will use temporal domain and spatial domain. In the temporal domain the analysis compares the trend of the original temporal trend with the FFT temporal filtered trend. In spatial domain the analysis compares the original image with the FFT filtering results, the comparison will do for all image in a year.

3. Results and discussions
3.1. FFT filtering
Figure 3 (a) is the sample backscattered temporal series from one pixel of paddy field area in Subang. It can be seen that the backscattered consist of noise, because the trend is not natural. This pixel area is planted by paddy 3 times a year, so the backscattered trend must be with 3 peaks. The FFT filtering was applied to remove this noise. Figure 3 (b) shows the frequency domain of FFT-1 to FFT-5. FFT-1 means that there is 1 wavelength in the certain period, FFT-2 means that there are 2 wavelengths in certain period, FFT-i means that there are i number of wavelengths in certain period. Adding the FFT1 to FFTn denote by FFT1-FFTn is the results of FFT filtering, this filter deletes or obey the rest of FFT. If n is a number of data series, so FFT1-FFTn is exactly similar with the original data. From figure 3 (b), the highest amplitude of the wave is FFT3. The highest amplitude indicates the number of main peaks in the trend of original data. It can be seen that the number of peaks in the original trend is three. Figure 3 (c) is the results of FFT filtering, FFT1-FFT2, FFT1-FFT3, until FFT1-FFT5. The number of peaks for FFT1 and FFT1-FFT2 is 1 peak, it means that the FFT1 is dominant or the amplitude of FFT1 is larger than FFT2. Number of peaks of FFT1-FFT3 to FFT1-FFT5 is three, it means that the FFT3 is dominant compare with FFT4 and FFT5. The more FFT used for filtering the more similar with the original data. The figure 3 (d) shows that the FFT filtering of FFT1-FFT5 is easier and more reasonable to explain the paddy growth in this location. The lowest backscatter indicated paddy field was flooded, then the vegetation was growth until the maximum value, then the paddy was harvested.

The used of period for this filtering must be a year or one cycles of paddy growth. In every year the cycles of paddy growth usually are similar with the previous one. The end value of FFT filtering results is connected to the beginning of FFT filtering results, its continuous wave.
Figure 3. Explanation of FFT temporal filter results

3.2. FFT filter results
The input of FFT filtering are 31 images of Sentinel-1 with 2 polarization, so the FFT filtering results are 31 images, 2 polarization and 6 scenarios of FFT filtering.

| Sentinel-2 | Sentinel-1 Before FFT filtering | Sentinel-1 After FFT filtering: FFT1-FFT5 |
|------------|----------------------------------|-------------------------------------------|
| RGB SWR,NIR, Red |                                  |                                           |

Figure 4. Comparison between Sentinel-2, and Sentinel-1 original data and FFT filtering results: FFT1-FFT5 (acquisition date: 17 January 2020) on center location: 107.7926, -6.4253 (above) and center location: 107.9124, -6.4388 (below)

Total images results are 31x6=186 images with two polarizations. The results discussion separates into three parts, (1) spatial comparison, and (2) correlation analysis comparison. Spatial comparison was done for selected sample only, it compares the original data and FFT filtering. The correlation
analysis comparison compare all scenario results for VH polarization only, because of the VH polarization is more related with the paddy growth [16].

3.3. Spatial comparison results

Figure 4 shows the image of Sentinel-2 optical image (left), Sentinel-1 before FFT filtering (center) and results of FFT filtering FFT1-FFT5 (right) from same acquisitions date (January 17th 2020). There are two sample locations, sample location 1 in figure 4 (a) (b) and (c), and sample location-2 in figure 4 (d) (e ) (f). Globally, the images before and after FFT filtering have the similar color contras. The mean and deviation of both images are similar, the mean and standard deviation is -16.87 db (mean original), -16.35 db (mean filter), and 3.89 db (deviation of original image), and 3.67 db (deviation of filtered image). In the location-1, the homogeneity texture in the FFT filtering result is higher, it can be seen in figure 4 (c). The land-cover object in the filter image is easier identified and easier in delineating between each object. In general, visually the filter result is easier for land-use identification, especially in paddy field identification and monitoring. In the location-2, the original image cannot be used to separate the paddy field in the bare soil condition with the mix-plantation and village, but after FFT filtering the paddy field separated well.

![Figure 4](image)

**Figure 4.** Comparison of original image and 5 from 6 scenarios of FFT filtering for Sentinel-1 data on (a) Original Image (b) FFT filtering: FFT1-FFT2 (c) FFT filtering: FFT1-FFT3 (d ) FFT filtering: FFT1-FFT4 (e ) FFT filtering: FFT1-FFT5 (f ) FFT filtering: FFT1-FFT8

The Figure 5 shows the comparison the original image with five from six difference scenarios of FFT filtering. Generally, the all scenarios are similar with the original one. Figure 5 (b) and (c ), the paddy field area in the upper right corner are more contras and the color is light green, it is little difference with the original. The image correlation of VH polarization from these two-filter scenarios and the original one are less than 0.88. In the Figure 5 (d) (e ) and (f), visually the color and contras is difficult to differentiate with the original image, all the image correlation of VH backscatter and original image are above 0.88.

![Figure 5](image)

**Figure 5.** Comparison of original image and 5 from 6 scenarios of FFT filtering for Sentinel-1 data on 6 Nov’ 2019
3.4. Statistical results

The results in figure 6 show that increasing the number of FFT in filtering processing, the correlation is increase. The FFT1-FFF3 filtering has the average correlations is 87%, but some acquisition still has the correlation less than 85%. If we use the threshold of 85% for correlations from all acquisition, the optimum filtering is FFT1-FFT5 filtering with the average correlation from all data is around 92%. Generally, the FFT filtering results with correlation of 85% or higher, the backscattered trend of paddy growth could be identified better, so this technique is recommended for paddy growth monitoring.

Figure 6. Correlation results from 6 (six) difference scenarios

4. Conclusions

The SAR images contain of speckle noise; it can be reduced using spatial and temporal processing methods. This research proposes the noise reduction algorithm using FFT of temporal data. The one year of sentinel-1 was used corresponding to the period of the paddy growth cycle. The optimum result was selected by comparing the six scenarios of the FFT filtering using the correlation value of the original image and the results of FFT filtering. The results show that the correlation is increased by increasing the number of FFT in the filtering process. The minimal FFT filtering uses FFT1-FFF3 filtering, with the average correlations being 87%, but some acquisition still has a correlation of less than 85%. The optimum is using filtering FFT1-FFT5. The average correlation of all data is 92%, and all correlations are above 85% for all data during a year. Using the optimum scenario above, paddy growth's backscattered trend could be identified as better and easier, so this technique is recommended for paddy growth monitoring.

Acknowledgments

Authors would like to thank to Indonesian National Institute of Aeronautics and Space (LAPAN) for providing processing facilities, Faculty of Mathematics and Natural Science - University of Indonesia (FMIPA UI) for providing remote sensing research laboratory and dissemination and Indonesian Ministry Research and Technology for providing budget publication.

References

[1] Rajamani A 2014 Performance Analysis Survey of Various SAR Image Despeckling Techniques Int. J. Comput. Appl. 90 5–17
[2] Dewaele P and Wambacq P 1994 Speckle filtering of synthetic aperture radar images: A Review Speckle Filtering of Synthetic Aperture Radar Images: A Review Remote Sens. Rev. 8 313–40
[3] Yommy A S, Liu R and Wu A S 2015 SAR Image Despeckling Using Refined Lee Filter 2015 7th International Conference on Intelligent Human-Machine Systems and Cybernetics vol 2 pp 260–5
[4] Zhu J, Wen J and Zhang Y 2013 A new algorithm for SAR image despeckling using an enhanced Lee filter and median filter 2013 6th International Congress on Image and Signal Processing (CISP) vol 01 pp 224–8
[5] Qiu F, Berglund J, Jensen J R, Thakkar P and Ren D 2004 Speckle Noise Reduction in SAR Imagery Using a Local Adaptive Median Filter Speckle Noise Reduction in SAR Imagery
Using a Local Adaptive Median Filter GIScience Remote Sens. 41 244–66

[6] Mahdian M, Motagh M and Akbari V 2013 Image Enhancement and Speckle Reduction of Full Polarimetric Sar Data By Gaussian Markov Random Field ISPRS - Int. Arch. Photogramm. Remote Sens. Spat. Inf. Sci. XL-1/W3 263–7

[7] Ansari R A and Mohan B K 2014 Noise filtering of remotely sensed images using iterative thresholding of wavelet and curvelet transforms Int. Arch. Photogramm. Remote Sens. Inf. Sci. - ISPRS Arch. 40 57–64

[8] Roomi S M M, Kalaiyarasi D, Abhainaya J G and Bhavana C 2011 Edge Preserving SAR Image Despeckling Third National Conference on Computer Vision, Pattern Recognition, Image Processing and Graphics pp 130–3

[9] Wang X, Ge L and Xiaoqing L 2012 Evaluation of Filter for Envisat ASAR Speckle Suppression in Pasture Area ISPRS Ann. Photogramm. Remote Sens. Spat. Inf. Sci. 1 341–46

[10] Ghani H A, Razwan M, Malek A, Fadzli M, Azmi K, Muril M J and Azizan A 2020 A review on sparse Fast Fourier Transform applications in image processing Int. J. Electr. Comput. Eng. 10 1346–51

[11] Yang X, Li X-Y, Li J-G, Ma J, Zhang L, Yang J and Du Q-Y 2014 Research on fast Fourier transforms algorithm of huge remote sensing image technology with GPU and partitioning technology. Guang pu xue yu guang pu fen xi 34 498–504

[12] Oberst U 2007 The Fast Fourier Transform SIAM J. Control Optim. 1–45

[13] Oraintara S, Chen Y J and Nguyen T Q 2002 Integer fast Fourier transform IEEE Trans. Signal Process. 50 607–18

[14] Sentinel-1 T 2013 Sentinel-1 User Handbook (European Space Agency)

[15] Vincent P, Bourbigot M, Johnsen H and Piantanida R 2020 Sentinel-1 Product Specification (ESA)

[16] Lestari A I, Kushardono D and Sensing R 2019 The use of C-Band Synthetic Aperture Radar Satellite Data for Rice Plant Growth Phase Identification Int. J. Remote Sens. Earth Sci. 16 31–44