A New Approach for SAR Image Denoising

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ABSTRACT

In synthetic aperture radar (SAR) imaging, the transmitted pulses from space born antenna interacts with ground objects and returned energy or back scattered energy will be collected to get backscattered image. In this process, a speckle noise will be added because of the coherent imaging system and makes the study of SAR images very difficult. For better SAR image processing, the speckle has to be removed in the initial stages of processing and maintain all texture features efficiently. The BM3D method is generally considered as state of art method in denoising of SAR images. In this paper, it is proposed a technique to despeckle the speckle noise to the maximum extent while maintaining the edge characteristics.
But still the BM3D method is generally considered as state of art method in denoising of images and despeckling of SAR images [15]. The compressive sensing based 3D (CS3D) despeckling framework is comprised of three major steps: selection of subsets of pixels from SAR images, reconstruction of SAR image from each subset of pixels using CS theory, and statistical combining of multiple reconstructed images by employing selective 3D filtering. In this paper, we proposed a technique to despeckle the SAR images to the maximum extent while maintaining the edge characteristics. We compared our proposed method with state-of-art methods in terms of quality parameters like ENL, SSI, PSNR and ESI.

2. DE-SPECKLING METHODS

2.1. BM3D Method

The BM3-D algorithm contains two major steps. The first one contains transform domain hard thresholding to build a relatively clean image for estimating statistics, and the second one is having image denoising using wiener filtering in the same transform domain. In both the cases similarity between a group of blocks will be evaluated like in nonlocal approach. The size of the collected group will produce different responses. A combination of transform domain and spatial domain image denoising algorithms is presented in BM3D algorithm [16]. The selection of these thresholding levels vary the quality of output images and the selection of sub band in transform domain plays a major role in denoising the image.

The SAR-BM3D algorithm despeckles SAR images by combining the concepts of nonlocal filtering and wavelet hard shrinkage, which has a better capacity to preserve relevant details while smoothing homogeneous areas. However, the smoothing of homogeneous areas and the preserving of edges are still not well balanced in these methods. The BM3D method is generally considered as state of art method in denoising of images and despeckling of SAR images as Figure 1.

2.2. CS3D Method

The compressive sensing (CS) theory proved that any sparse signal or image can be reconstructed from samples fewer than number of elements in a signal or image [17]. These subsets are taken as measurement vectors in CS framework to obtain multiple SAR images by solving convex optimization problem. The pixel-wise averaging of multiple compressive reconstructed images would lead to better results compared to conventional despeckling techniques. In this work, employ selective 3 dimensional (3D) filtering of multiple reconstructed images to further improve despeckling results.

This despeckling framework is comprised of three major steps; selection of subsets of pixels from SAR images, reconstruction of image from each subset of pixels using CS theory, and statistical combining of multiple reconstructed images by employing selective 3D filtering, as shown in Figure 2.
2.3. Proposed Method

The radar image will be cropped according to user's applications size. If the image is in geotiff format, generally it is noise free one; otherwise it is contaminated with noise. The necessary sized image will be given to non decimated wavelet transform and extract the all possible coefficients from it. After separating the coefficients, the required coefficients will be collected and they will be given to inverse non decimated wavelet transform.

The output image of previous step will be divided into different blocks with a fixed size. Each block will be compared with other blocks and euclidean distance will be calculated. If the distance is below a threshold value, then the block will be given to discrete wavelet transform and the coefficients will be extracted. Manipulation of coefficients will be done and an inverse discrete wavelet transform will be applied to reconstruct the image as shown in Figure 3.

The last obtained image will be given to discrete wavelet transform once again and calculate all possible coefficients. A wiener filter will be applied on specific set of coefficient values and an inverse discrete wavelet transform will be applied to reconstruct the image.

The quality parameters like equivalent number looks (ENL), speckle suppression index (SSI), correlation coefficient (CC), edge saving or preserving index (ESI) and peak signal to noise ratio (PSNR) will be measured for all the output images of different latest despeckling methods along with proposed algorithm.

1. Peak Signal to Noise Ratio (PSNR): PSNR is the ratio between the maximum signal power and the corrupting noise power. It is the factor that judges whether a method is providing good denoising scheme or not. Higher the value means higher image quality.

\[
\text{PSNR} = 10 \log_{10} \left( \frac{2^n - 1}{\text{MSE}} \right)
\]
2. Equivalent Number of Looks (ENL): Other than PSNR value, ENL value plays critical role in coherent systems like SAR processing. The ENL values speak about the efficiency in smoothing speckle noise of image over homogeneous areas.

\[
    \text{ENL} = \left( \frac{\text{mean}}{\text{standard deviation}} \right)^2 \tag{2}
\]

3. Coefficient of Correlation (CC): Correlation coefficient gives how far the two images correlated to each other, that means how far the despeckled image is near by the original image. It indicates the strength of linear relationship between the original \(x\) and denoised images \(\hat{x}\). If the value is near to 1, then there exists stronger positive correlation between the \(x\) and \(\hat{x}\) image.

\[
    C_{x,\hat{x}} = \frac{E[(x-\mu_x)(\hat{x}-\mu_{\hat{x}})]}{\sigma_x \sigma_{\hat{x}}} \tag{3}
\]

where \(\mu_x\) and \(\mu_{\hat{x}}\) are mean values of original and despeckled SAR images respectively and \(\sigma_x\) and \(\sigma_{\hat{x}}\) are standard deviations of original and speckle removed images respectively.

4. Speckle Suppression Index (SSI): The ratio of standard deviation to mean is used to measure the speckle strength in an image. Let \(x\) and \(\hat{x}\) are original and despeckled SAR images. The SSI plays a critical role in radar image processing steps. It is defined as

\[
    \text{SSI} = \frac{(\text{var}(\hat{x}))^{1/2}}{(\text{mean}(x))} \times \frac{(\text{mean}(x))}{(\text{var}(x))^{1/2}} \tag{4}
\]

It should be less than 1. Lower the value means higher the speckle reduction. Ideal value is zero.

5. Edge Save Index: Edge save index (ESI) explains the capability of the image how far the edge properties have been maintained.

\[
    \text{ESI}_h = \frac{\sum_{i=1}^{m} \sum_{j=1}^{n-1} |x(i,j+1) - \hat{x}(i,j)|}{\sum_{i=1}^{m} \sum_{j=1}^{n-1} |x(i,j+1) - x(i,j)|} \tag{5}
\]

\[
    \text{ESI}_v = \frac{\sum_{j=1}^{n} \sum_{i=1}^{m-1} |x(i,j+1) - \hat{x}(i,j)|}{\sum_{j=1}^{n} \sum_{i=1}^{m-1} |x(i,j+1) - x(i,j)|} \tag{6}
\]

where \(\hat{x}\) is recovered image; \(x\) is original SAR image; \(m\) and \(n\) are the number of rows and columns of the SAR image.

3. EXPERIMENTAL RESULTS

All the filtering and transform domain techniques will be applied and tested mainly to the images of RISAT-1 sensor. Table 1 gives different quality factor values to test image. Generally ENL value plays a major role in deciding the despeckle algorithm to be used in microwave image processing. The higher the value of ENL, the better the performance of despeckling technique. Among all the techniques, the proposed method gives better ENL value.

Along with ENL value, SSI is an important parameter in the field of SAR imagery. Generally, speckle suppression index is less than 1. Lower the value means higher the speckle reduction. Among all the techniques, the proposed method gives least SSI value. That means maximum speckle has been removed.

Correlation coefficient gives how far the two images correlated to each other, that means how far the despeckled image is near by the speckled image. From table 2, we can say that our method gives better CC value.

Edge save index is the critical parameter in any denoising method. Without better edge saving parameter, any method holds nothing. It can be observed that the proposed technique gives better ESI values among all methods. Similarly, the PSNR value that is obtained by the proposed method is high. It can be noted that, our despeckling technique performs better than other methods in quality factors terms of ENL, SSI, CC, ESI and PSNR. The despeckling results of the proposed technique and other methods to image are given in Figure 4 and Table 2. The PSNR values for different despeckling techniques on different RISAT-1 images have been given in Figure 5.

The area that we considered for despeckling is MAYKOP, RUSSIA. The central latitude and longitude values are 44.609 and 40.094 respectively. The characteristics of the scene have been given below in table 1. It is a RISAT-1 coarse resolution scanSAR mode CRS data.
Table 1. Characteristics of Data

| Characteristic                        | Value                  |
|--------------------------------------|------------------------|
| Radar Carrier Frequency              | 5.35 GHz (C-band)      |
| Incidence angle                      | 41.337 Deg             |
| Polarizations                        | HH                     |
| Datum                                | WGS 84                 |
| Sensor height at the equator         | 541 km                 |
| Revisit time (Orbit repeat cycle)    | 12 days                |
| Resolution                           | 36 meters              |
| Mode                                 | ASCENDING              |
| Sensor Look                          | Right                  |
| Mean Local Time                      | 6 AM                   |

Table 2. Quantitative comparison of despeckling techniques for RISAT-1 data

| Method     | ENL    | SSI    | CC    | ESI    | PSNR   |
|------------|--------|--------|-------|--------|--------|
| LEE        | 17.74184 | 0.287047 | 0.511941 | 0.249804 | 10.76049 |
| WAVELET    | 0.474352 | 0.584496 | 0.593618 | 0.170258 | 11.40477 |
| CURVELET   | 0.565033 | 0.677036 | 0.73331  | 0.334237 | 17.94699 |
| PCA-LPG    | 0.571852 | 0.433772 | 0.773526 | 0.274861 | 14.24952 |
| BM3D       | 11.34283 | 0.52347  | 0.906364 | 0.624499 | 16.99552 |
| CS3D       | 12.0902  | 0.07775  | 0.905526 | 0.620749 | 16.95302 |
| PROPOSED   | **25.97077** | **0.054731** | **0.961631** | **0.688664** | **27.22432** |

Figure 4. RISAT-1 dataset: Rural area near maykop city in Russia. (512*512) (a) Original, (b) Noisy, (c) Lee, (d) Wavelet, (e) Curvelet, (f) PCA-LPG, (g) BM3D, (h) CS3D and (i) Proposed.

The other study area is considered in the work is located on the east coast of India at a latitude of 17°42' North and longitude of 83°23' East and the time zone is GMT + 5:30. It is one of famous and major ports in India and the biggest port of Andhra Pradesh state. It is Visakhapatnam Port area. The table 3 shows the characteristics of the TerraSAR-X data. The despeckling results of the proposed technique and other methods to image are given in Figure 5 and Table 4.
Table 3. Characteristics of TerraSAR-X Data

| Parameter                                      | Description                              |
|-----------------------------------------------|------------------------------------------|
| Radar Carrier Frequency                       | 9.65 GHz (X-band)                        |
| Incidence angle range for:                    |                                          |
| Strip map/ScanSAR modes                       | 20°-45° full performance                 |
| SpotLight modes                               | 20°-55° full performance                 |
| SpotLight modes                               | (15°-60° accessible)                     |
| Polarizations                                 | HH,VH,HV,VV                              |
| Pulse Repetition frequency                    | 2.2KHz-6.5KHz                            |
| Nominal orbit height at the equator           | 514 km                                   |
| Revisit time (Orbit repeat cycle)             | 11 days                                  |
| Inclination                                   | 97.44°                                   |
| Ascending node                                | 18:00 +/- 0.25hr (local time)            |
| Equatorial Crossing time                      |                                          |

Table 4. Quantitative comparison of despeckling techniques for TerraSAR-X data

| Technique   | ENL   | SSI   | CC    | ESI   | PSNR  |
|-------------|-------|-------|-------|-------|-------|
| LEE         | 10.5816 | 0.2525 | 0.5851 | 0.2619 | 12.6038 |
| WAVELET     | 0.3666  | 0.6509 | 0.6518 | 0.1656 | 13.2074 |
| CURVELET    | 0.2209  | 0.8803 | 0.8836 | 0.4415 | 18.3666 |
| PCA-LPG     | 0.2259  | 0.8456 | 0.9914 | 0.6940 | 25.7749 |
| BM3D        | 11.4807 | 0.4265 | 0.9096 | 0.6113 | 18.4295 |
| CS3D        | 12.0543 | 0.0757 | 0.9118 | 0.6172 | 18.5273 |
| PROPOSED    | 12.8160 | 0.0583 | 0.9691 | 0.6877 | 27.9941 |

(a) Original, (b) Noisy, (c) Lee, (d) Wavelet, (e) Curvelet, (f)PCA-LPG, (g) BM3D, (h) CS3D and (i) Proposed

Figure 5. TerraSAR-X dataset: Visakhapatnam Port area in India. (512*512) (a) Original, (b) Noisy, (c) Lee, (d) Wavelet, (e) Curvelet, (f)PCA-LPG, (g) BM3D, (h) CS3D and (i) Proposed

The proposed method consists of BM3D method along with unsampled decimation. The decimation reduces the quality of the image that is to be denoised. It is because of down sampling at transmitting end and upsampling at receiving end in wavelet transformation. The conversions of sampling are
avoided in our proposed method. The PSNR values for different despeckling techniques on different RISAT-1 images (Circular Fine resolution stripmap mode-Right Horizontal (Image-1), Circular Fine resolution stripmap mode-Right Vertical (Image-2), coarse resolution scanSAR-Horizontal Horizontal (Image-3), coarse resolution scanSAR- Horizontal Vertical (Image-4)) have been given in Figure 6.

Figure 6. PSNR values for different images

4. CONCLUSIONS
We tested with different existing algorithms and proposed algorithm on different images of different modes of RISAT-1 images and TerraSAR-X images. They have been tested with different noise levels (variances of 0.1, 0.25 and 0.5) and different standard sizes (256*256 and 512*512). We considered different modes of RISAT-1 like coarse resolution scanSAR mode (CRS), medium resolution scanSAR mode (MRS), fine resolution stripmap mode (FRS) and different polarized images (HH, HV, VH, VV, RH and RV) of RISAT-1 for testing. We also tested on different TerraSAR-X images and measured different quality parameters.

Even though the lee filter removes much speckle, it cannot preserve the edge details and it does not maintain the correlation with input image. It is a major drawback in statistical filters. The transform domain techniques convert the SAR image data into different frequency band in which the signal and noise are separated. The elimination of noise is simple at that moment. Because of this particular reason the transform based techniques will produce significant peak signal to noise ratios. Whereas the latest block based techniques like BM3D and CS3D are preserving the edge details and suppress the speckle better, but proposed method preserves edges and suppress the speckle much better than BM3D and CS3D techniques.

It is evidently observed that the proposed despeckling technique performs better than other latest methods in terms of quality factors like ENL, SSI, CC, ESI and PSNR.

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