Speckle De-Noising of Synthetic Aperture Radar (SAR) Images Using Adaptive Non-Local Means (NLM) Filter

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Abstract— **Synthetic Aperture Radar (SAR) is a coherent radar system that is widely used to produce high-resolution images of the earth. Due to its comprehensible nature, SAR images are adversely stimulated by speckle noise which is a multiplicative noise and is difficult to eliminate by classic de-noising filters. The commonly used non-local means filter is not optimal for these images because image noise prevents precise determination of the correct coefficients for averaging, leading to over-smoothing and other artifacts. So, we implement an adaptive version of non-local means approach to de-noise such images to improve their appearance. This adaptive method addresses this problem by first smoothing the noisy image, then applying k-means approach to smoothed image which divides the image into various clusters and then applying non-local means filter to different clusters. We show that this adaptive non-local means approach provided more efficient results in de-noising the SAR images as compared to old non-local means filter.**

***Index Terms*— De-noising, non-local means (NLM), speckle, Synthetic Aperture Radar (SAR)**

I. Introduction

The Synthetic Aperture Radar (SAR) is an active sensor used for obtaining high level resolution images of the earth. SAR uses microwave signals for transmission and detects the waves reflected back by various objects to create fine resolution images. It is very useful for providing information about earth's surface by using the relative motion between a moveable antenna and its target. It is mounted on a moving platform such as an aircraft, spacecraft and is widely used in oceanography, remote sensing, resource monitoring, navigation, geology etc. The Synthetic Aperture Radar (SAR) imagery has become an advantageous and important application over the optical satellite imagery because of its ability to operate in any weather conditions. There are numerous advantages of SAR over satellite imagery techniques, such as, its ability to penetrate clouds, soil and forest canopy. In spite of all these advantages, SAR images are prone to speckle noise which is granular in nature and affects the radiometric resolution and degrades the quality of the image.

Speckle Noise

Speckle noise is a multiplicative noise that reduces the quality of SAR images. It is a granular noise and affects the appearance of the SAR images by making recognition of various captured objects challenging. Speckle noise is difficult to remove as it correlates itself with each pixel in the image and making the de-noising process complex. Statistically, speckle can be regarded as a random walk process as studied Goodman [1].

De-speckling

De-speckling an image is a tedious task due to the multiplicative nature of the speckle noise. There are various filters for de-speckling such as Lee filter, Frost filter, Kuwahara filter, Median filter, Hybrid median out of which Non-local Means (NLM) Filter by Buades et al. [2] provided the most promising results of all. Then an adaptive version of the classic NLM filter was introduced by Peter et al. [3] to produce better de-noised images.

In this work, we have implemented adaptive NLM filter on SAR images for de-speckling and to get better de-noised images. In order to make NLM adaptive, the speckled image is firstly smoothed using Gaussian Filter, then segmenting the resultant image using k-means clustering and finally applying the nonlocal-means to the resultant

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clusters. In our work, it is shown that applying adaptive NLM on speckled SAR images resulted in more efficient de-speckled images and made the various objects in the image more recognizable.

II. Non-local Means

Non-local means filter was proposed by the Buades et al. [2]. It replaces each pixel value with the weighted average of other pixels whose neighborhood has a similar geometric configuration, averaging of these pixels result in noise cancellation and obtain original pixel value. In the NLM filter, the intensity values of the pixels can be related to the pixel intensity of the entire image. The expression for the restored intensity of a pixel x_i is:

$$\mathrm{NL}(u)(x_i) = \sum_{x_j \in \Omega} w(x_i, x_j)\, u(x_j) \qquad (1)$$

Here $w(x_i, x_j)$ denotes the weight given to $u(x_j)$ in order to reinstate the pixel x_i. The $w(x_i, x_j)$ estimates the similarity between x_i and x_j, with the constraints such as $w(x_i, x_j) \in [0,1]$. The weights are calculated by the equation:

$$w(x_i, x_j) = \frac{1}{Z_i} e^{-\frac{\|u(N_i) - u(N_j)\|^2_{2,a}}{h^2}} \qquad (2)$$

Where Z_i is the normalization constant given by the equation:

$$Z_i = \sum_j e^{-\frac{\|u(N_i) - u(N_j)\|^2_{2,a}}{h^2}} \qquad (3)$$

And the parameter h acts as a degree of filtering.

III. Adaptive Technique

The adaptive technique was proposed by Peter et al. [3]. In order to make NLM adaptive, they divided the whole process into three steps:
i. Smoothing the image using Gaussian filter
ii. Segmenting the image using k-means clustering
iii. Image matching using a mask function

Smoothing the image

The noisy image is first smoothed using Gaussian filter because it helps in reducing noise and unnecessary artifacts, which results in efficient segmentation of the image in next step. Gaussian filter is given by:

$$g(x, y) = \frac{1}{2\pi\sigma^2} e^{-\frac{x^2 + y^2}{2\sigma^2}} \qquad (4)$$

Where x and y are the pixel co-ordinates of the resultant image and σ is the standard deviation of the Gaussian distribution.

Image Segmentation

Based on its gray-level intensity, the image is then segmented and clustered using k-means clustering which is given by:

$$v = \sum_{i=1}^{k} \sum_{x_j \varepsilon S_i} \left\| x_j - \mu_i \right\|^2 \qquad (5)$$

Where there are clusters S_i, i= 1, 2,…, k and μ_i is the centroid of all the points x_j in the cluster S[4]. As the input image changes, the number of clusters for that input image also changes.

Image Matching

In this step, the output of each segmented cluster obtained in previous step is matched with the original noisy image in order to get appropriate parts for mask function.

Adaptive NLM filter

The de-speckled value $\hat{g}_n(i)$ at pixel *i* is obtained by taking weighted average of the pixels in its neighborhood. It is considered as adaptive because the input to NLM is of close to geometrical pattern as input for de-noising by intensity level clustering.

$$\hat{g}_n(i) = \frac{1}{\lambda(i)} \sum_{j \in \Omega_s} w(i, j) f_n(j) \qquad (6)$$

Here, n is the number of clusters, n=1, 2, …, k.

IV. Experimentation and Results

In this work, we have applied adaptive NLM on 30 speckled SAR images (10 sample images of urban area, terrestrial area and vegetation area each) to differentiate the de-speckled results from both NLM and adaptive NLM filter. In this paper, we have shown 3 sample images. The parameter *h* was taken as 10* σ (standard deviation). The standard deviation of Gaussian filter in adaptive NLM was taken as 10 and the filter size was taken as 3X3. Then we calculated PSNR (Peak Signal-to-Noise Ratio) from both the filters and compared the results. The results of both qualitative analysis (visual analysis) and quantitative analysis (PSNR) are summarized in Figure-1 and Table-I.

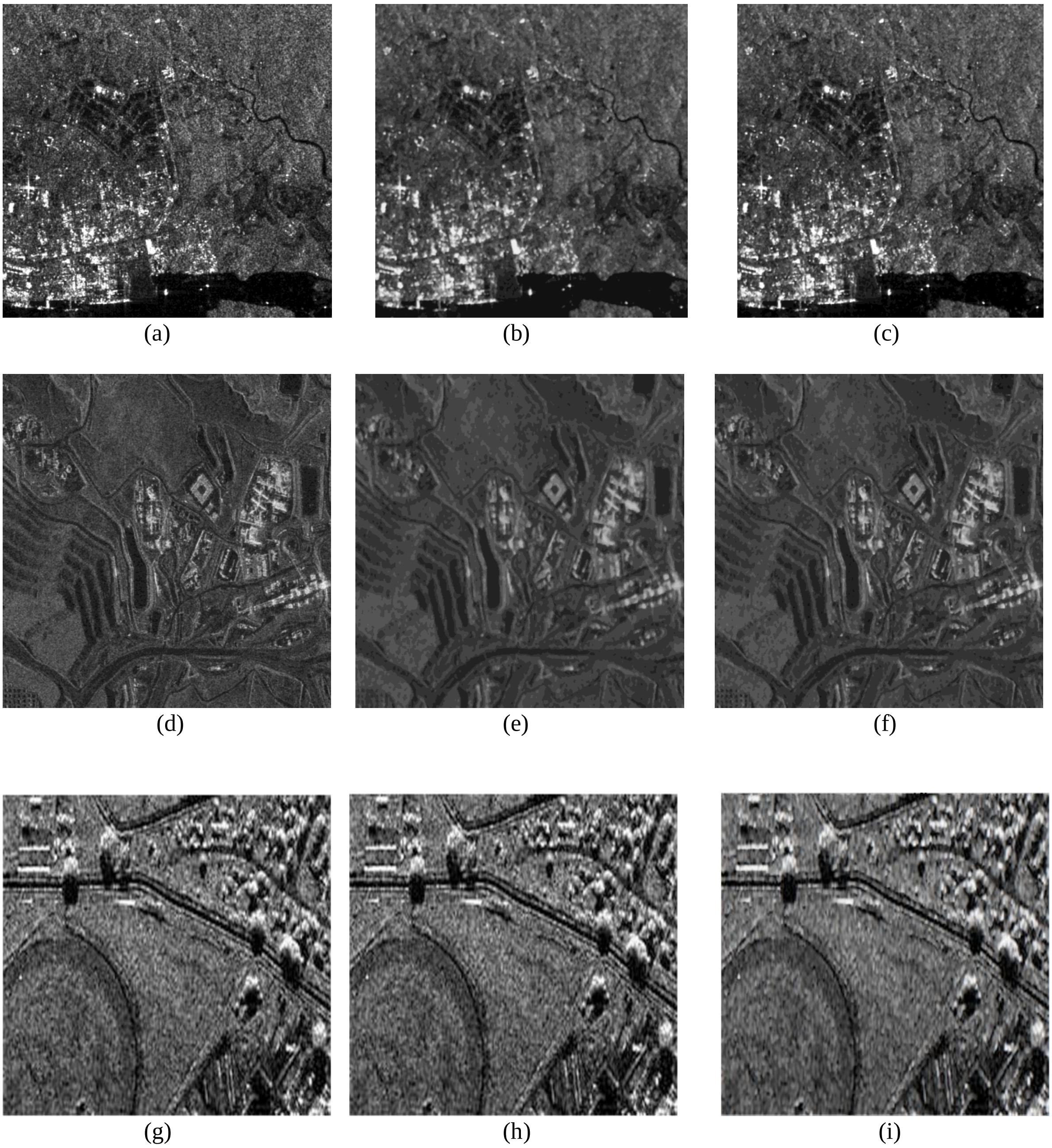

Fig.1. a) Noisy urban area image, b) De-speckling urban area image with NLM, c) De-speckling urban area image with adaptive NLM, d) Noisy terrestrial area image, e) De-speckling terrestrial area image with NLM, f) De-speckling terrestrial area image with adaptive NLM, g) Noisy vegetation area image, b) De-speckling vegetation area image with NLM, c) De-speckling vegetation area image with adaptive NLM

Table I. PSNR analysis of de-speckled images using NLM and adaptive NLM

Image	**PSNR using NLM**	**PSNR using adaptive NLM**
Urban area	23.544465	24.744857
Terrestrial area	27.460566	28.387095
Vegetation area	28.537461	29.631658

As in Fig.1, classic NLM filter de-speckled the image effectively but the de-speckled image obtained was excessively smoothed which lead to blurring of the edges. In contrast to it, adaptive NLM preserved the edges effectively during the de-noising process and objects were more recognizable in the resultant image. Moreover, as shown in Table I, adaptive NLM provided significant results in terms of peak signal-to-noise ratio (PSNR) of the image.

V. Conclusion

In this paper, we have implemented adaptive non-local means filter to de-speckle SAR images. Adaptive NLM efficiently de-speckled the image in contrast to classic NLM filter and provided more convincing results. The de-speckled images obtained were of high quality, objects in the image were more recognizable and distinguishable. Unlike classic NLM filter, adaptive NLM did not result in over smoothing the image and preserved the edges and other significant details in a better way. Further scope of this paper includes improving the performance of the filter by reducing the complexity of adaptive NLM and applying better segmentation technique.

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