Speckle Reduction of SAR Images using Adaptive Sigmoid Thresholding and Analysis of various Filtering Techniques

V. Santhi
School of Computing Science and Engineering
VIT University
Vellore

Chandra Mouli P.V.S.S.R.
School of Computing Science and Engineering
VIT University
Vellore

Arunkumar Thangavelu
School of Computing Science and Engineering
VIT University
Vellore

ABSTRACT
In this paper, an effective method for speckle reduction and image enhancement for SAR images is proposed. The novelty of the proposed method is the adaptive calculation of parameters with ease in adaptive sigmoid thresholding approach for removing the speckle noise from the SAR images followed by post-processing operation. The noise removal operation is carried out in wavelet domain using db4 wavelet. The experimental results show that the proposed method despeckles the given image efficiently. Filtering is done as post-processing operation. Comparative analysis of various filters has been carried out and the results prove that Gaussian filtering is more appropriate for enhancing the quality of despeckled SAR images.

General Terms
SAR Image Processing, Information Security, Digital Watermarking.

Keywords
Despeckling, Adaptive sigmoid thresholding, SAR Image enhancement, Wavelet decomposition, Gaussian filter.

1. INTRODUCTION
Synthetic Aperture Radar (SAR) is used for capturing high resolution images from higher altitudes. SAR is capable of operating under any climatic changes. Remote places where human finds difficult to reach and remotely located objects at those places can be easily captured by SAR. [1]. SAR images finds applications in different fields such as remote sensing, for mapping, surface surveillance, search and rescue, automatic target recognition etc. Radar sends the beam of light towards the earth's surface through a small aperture. The beam passes through various layers like ionosphere, stratosphere and enter into atmosphere and hit the surface of the object. Depending on the surface, the beam can be either reflected fully or partially, absorbed fully or partially or scattered. During the beam travel through different layers, the beam undergoes many atmospheric changes and that results in speckle. In general, every SAR image is affected by speckle noise and it is mandatory to remove it before further processing. Information in SAR image is of great importance, but speckle noise degrades the image quality severely.

The goal of despeckling is to remove noise and to preserve all textural features in the SAR images. The despeckled image is used to further study the textural content, identify the objects and boundaries. Hence it is necessary to analyze and design the speckle noise removal algorithms from SAR images. The literature reveals many algorithms for speckle removal but most of them are based on some input from the user either for thresholding for some other parameters. Hence noise reduction in SAR images is still an active research area.

This motivates the authors to propose a fully adaptive method for removing the speckle noise from a SAR image without any human intervention.

2. LITERATURE REVIEW
In this section, a brief review on speckle noise removal is discussed.

Many different methods for SAR image despeckling have been proposed over the past years. Sveinsson and Benediktsson [1] modeled speckle noise as multiplicative Rayleigh noise and proposed a sigmoid thresholding method for SAR images in the wavelet domain. The coefficients of thresholding for this method are based on the choice of parameters in the sigmoid thresholding function. The parameters are chosen empirically based on human visual perception. Fabrizio Argenti et al [2] proposed a method in which speckle reduction is approached as a minimum mean-square error (MMSE) filtering performed in the un decimated wavelet domain. They adaptively rescaled the detail coefficients. The empirical criteria based on distributions of multi scale local coefficient of variation calculated in the un decimated wavelet domain, are introduced to mitigate the rescaling of coefficients in highly heterogeneous areas where the speckle does not obey a fully developed model, to avoid blurring strong textures and point targets. The absence of decimation in the wavelet decomposition avoids typical impairments often introduced by critically sub sampled wavelet-based de-noising. Alin Achim et al proposed a novel Bayesian-based algorithm [3] within the framework of wavelet analysis where the sub band decompositions of logarithmically transformed SAR images are accurately modeled by alpha-stable distributions. The alpha-stable model is used to develop a blind speckle-suppression processor that performs a nonlinear operation on the data and this non-linearity is related to the degree of non-Gaussian of the data. Johannes R. Sveinsson et al [4] proposed another work in which they used two wavelet transformations for speckle reduction and enhancement of SAR images. A discrete wavelet transformation (DWT) is used based on a low pass and two high pass filters. This is followed by a discrete wavelet transformation based on two dual real wavelet trees is applied. Each tree produces a set of real DWTs, which together form the complex wavelet transformation (CWT). Both of these DWTs are almost translation invariant and are useful for speckle reduction through their sub band images, and the speckle reduction is obtained by thresholding the sub band image coefficients of the digitized SAR images. Min Dai,Cheng Peng et al [5] presented a wavelet-based despeckling method for synthetic aperture radar images and a Bayesian wavelet shrinkage factor to estimate noise-free wavelet coefficients is derived. To preserve edges during despeckling, they applied a modified ratio edge detector to the original image and the result is used in the despeckling framework. Dušan Gleich et al [6] proposed a wavelet-based algorithm for SAR image despeckling in which the Gauss–Markov Random Field (GMRF) is modeled as image and the noise is modeled as a Gaussian noise. It incorporates the Bayesian estimation technique in estimating the wavelet noise free coefficients. Sveinsson et al [7], proposed a method to select these parameters by minimizing an estimate of square error between the clean image and the de-noised one.

The rest of this paper is organized as follows. Section 2 gives brief description about 2D discrete wavelet transform and Section 3 describes the proposed work. Section 4 analyzes the experimental results, and conclusions are drawn in Section 5.

3. 2 D DISCRETE WAVELET TRANSFORM

The discrete wavelet transformation (DWT) technique for multi-resolution decomposition of images has been used for both noise reduction and compression of SAR images. The DWT provides a transformation of a signal from the time domain to the scale frequency domain. The 2-D wavelet transform can be implemented as a stage transformation. At the first stage the rows of the image being processed are low-pass (L) and high-pass (H) filtered and down-sampled by 2. Next each column of the row filtered image is again low-pass and high-pass filtered and down-sampled by 2. The output of each stage is then four sub band images labelled LL, LH, HL, and HH, respectively. Only the LL-sub band image goes through the same process of filtering and down-sampling to form the next stage of the structure. Every time a down-sampling is performed, the signal length is reduced by 2 [8].

3.1 Daubechies Wavelet

It is a family of wavelets having fractal structure and having different filter order with different length db1, db2, db4, db5 etc. Going for higher order filter length one should get efficient code processing and by selecting lower order one should get an image of less compressed information [9]. The higher order filter removes more texture content from images and lower order filter remove content of smooth region. Therefore, in this proposed work db4 wavelet is used for decomposition and noise removal.

4. PROPOSED WORK

The proposed methodology is discussed in detail in this section. This work uses sigmoid thresholding to de noise speckle affected SAR image. After that filtering process is done to enhance the quality of an image. Comparative analysis is carried out on four different kinds of filters. The objective metrics used are PSNR and entropy values. Figure 1 gives the architectural diagram detailed design of the work. The work is mainly divided into two phases, Image despeckling phase and Image enhancement phase, respectively

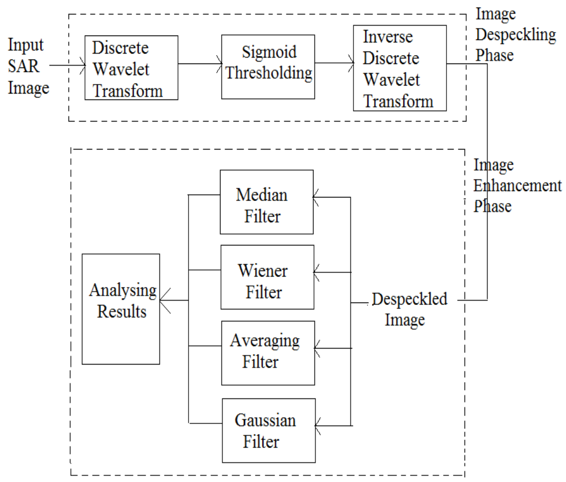

Fig 1: Architectural diagram for Image De-speckling

4.1 Image Despeckling Phase

The main function used in the Image despeckling phase is the sigmoid function. The sigmoid function is a function similar to the activation function commonly used in neural networks. For an input image, $\hat{y}$ with maximum absolute amplitude $\hat{y}_{max}$, the image range [$-\hat{y}_{max}$, $\hat{y}_{max}$] is mapped onto the interval [-1, 1] with the function $f(\hat{y})$ given by

$$f(\hat{y}) = a\hat{y}_{max}\left[sigmoid\left(c\left(\frac{\hat{y}}{\hat{y}_{max}} - b\right)\right) - sigmoid\left(-c\left(\frac{\hat{y}}{\hat{y}_{max}} + b\right)\right)\right] \quad (1)$$

where

$$a = \frac{1}{sigmoid\ (c(1-b)) - sigmoid\ (-c(1+b))} \quad (2)$$

and sigmoid($\hat{y}$) is defined by

$$sigmoid(\hat{y}) = 1/(1+\exp(-\hat{y})) \quad (3)$$

Because of the normalization, the transformation parameters, *a*, *b*, and c can be set independently of the dynamic range of the input image. In the proposed work we have chosen the parameters $c = sigmoid(10 * \sigma)$ and $b = sigmoid(10 * \sigma\ /\hat{y}_{max})$ where ŷmax is the maximum absolute amplitude value of subband images for the DWT multiresolution representation. The noise level (variance) σ in the DWT representation is not known in advance and has to be estimated from the image data. In this paper, an estimate of σ is taken to be the standard deviation of the high/high subband image of the first stage of each transformation. Also, no thresholding is carried out on the low/low subband image at the final stage of the transformation.

4.2 Image De-speckling Phase

Once SAR image is de-noised some of the information will be lost along with the speckle so enhancement should be performed on SAR images to increase the quality. Image enhancement is the improvement of digital image quality for visual inspection or for machine analysis without knowledge about the source of degradation which could be performed using linear operations in either the frequency or the spatial domain. It can be done by applying filtering operations to the image in frequency domain. In this paper we have applied four different types of filters and obtained results for each of them.

Input: Speckle affected SAR image
Output: Enhanced SAR image
The main steps of the algorithm are

1. Apply 4 level DWT using db4 wavelet to get the wavelet coefficients corresponding to the speckle affected image, $\hat{y}$.
2. Apply the non-linear function $f(\hat{y})$ using (1)
3. Apply the inverse orthogonal DWT to get the denoised image.
4. Perform filtering operations using Median filter, Wiener filter, Averaging filter, Gaussian filter to the de speckled SAR images
5. Calculate the PSNR and entropy values using different filters and perform comparative analysis.
6. Apply thresholding to extract the foreground object on the filtered image.
7. Apply morphological closing operation to get the final result.

5. EXPERIMENTAL RESULTS AND PERFORMANCE ANALYSIS

In this proposal the SAR images are de noised and its quality is enhanced. Figure 2 represents the speckle affected SAR image which will undergo sigmoid thresholding operation for de noising in frequency domain. In figure 3 and in figure 4 the wavelet decomposition and sigmoid thresholding of input image is shown respectively. Figure 3 shows the fourth level approximation coefficient and 4 levels of detailed coefficients and figure 4 represents these coefficients after sigmoid thresholding. Figure 5 shows the de-speckled SAR image, to which different types of filters are further applied for enhancing its quality.

Fig 2: Speckle affected SAR image

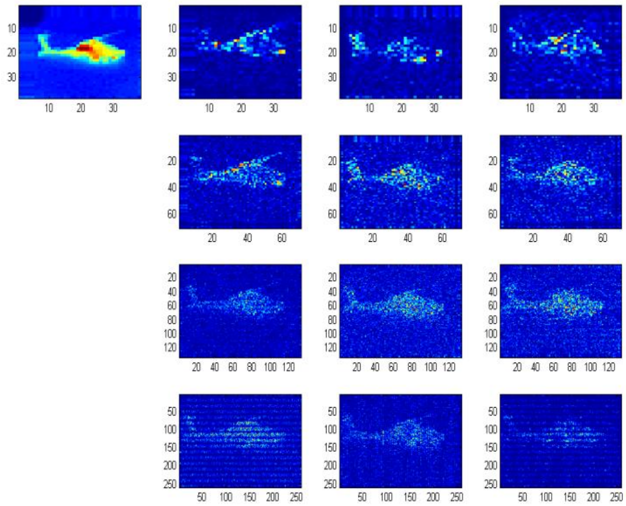

Fig 3: Approximation Band and Detail coefficients Band of DWT Output

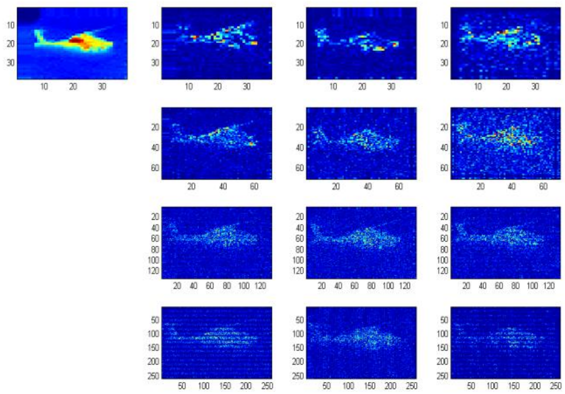

Fig 4: Sigmoid Thresholded Approximation and Detail coefficients Band

Fig 5: Despeckled SAR image

The de-speckled image obtained in step-5 is passed as input for thresholding. Thresholding converts the image into binary and separates the foreground portion from the background. Before applying thresholding, the filtered image is normalized. Using Otsu's method, the normalized filtered image is thresholded to extract the foreground portion. Finally morphological closing operation is done to extract the foreground object. The structuring element defined is a square matrix of size 3×3.

Figures 6 and 7 show the results of thresholding and morphological operations.

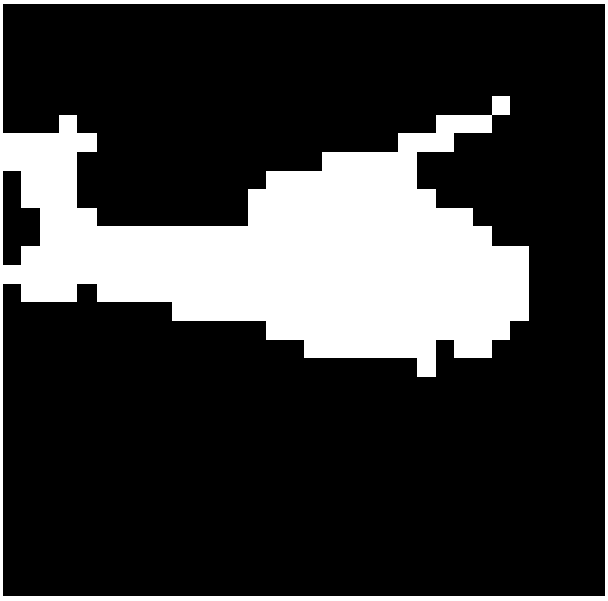

Fig 6: Thresholded image

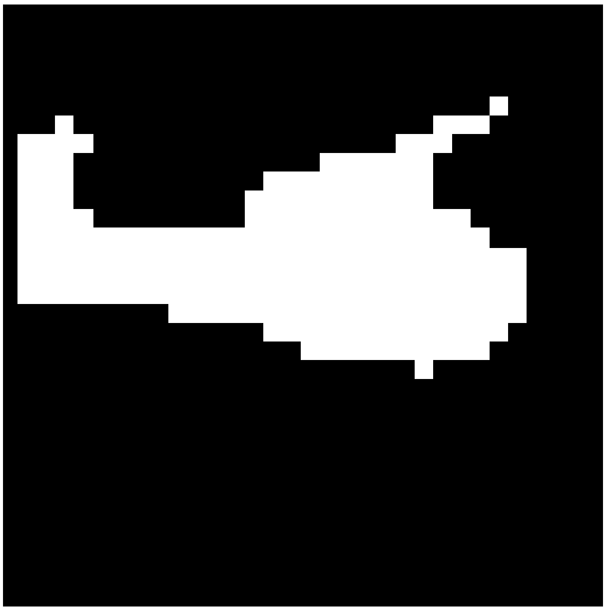

Fig 7: After morphological closing operation

In image enhancement phase, de-speckled SAR image is the input image to which filter operations are performed. Six different images are taken for performance analysis. Figure 7 to 10 shows the resultant images after filtering operations using median filter, Wiener filter, averaging filter and Gaussian filter respectively.

To analyze the efficiency of proposed algorithm the objective measures like PSNR and entropy values are obtained by testing different SAR images. Table 1 shows obtained PSNR between original image and the corresponding despeckled image. Table 2 shows obtained PSNR between despeckled image and the corresponding filtered images using different filters like median, Wiener, averaging and Gaussian filter. From these obtained results it is clear that the Gaussian filter gives the highest PSNR value and averaging filter gives the least value. So it is concluded that the Gaussian filter is would be used for de-speckling of SAR images. Similarly table 3 shows entropy values of all original images and also de-speckled images. It is observed that the entropy values of filtered images are lesser than that of de-speckled images as the noise content of de-speckled image is removed. To enhance the quality of de-speckled image filtering operation is carried out in frequency domain. Different filters are used to enhance image quality but Gaussian filter is found to be better in giving lower entropy value.

Table 1 PSNR Values using sigmoid thresholding

Name of Image name	PSNR Value in Decibels
Sar1.gif	25.83403
Sar2.jpg	28.24034
Sar3.jpg	27.51325
Sar4.jpg	28.51156
Sar5.jpg	27.92156
Sar6.jpg	30.11659

Table 2 PSNR values of despeckled images using different filters

Name of Image	Median filtering	Wiener filtering	Averaging filter	Gaussian filter
Sar1.gif	23.49930	25.97034	9.88037	34.91304
Sar2.jpg	26.03655	28.11326	10.68068	40.96072
Sar3.jpg	26.80308	29.42511	10.98702	41.26285
Sar4.jpg	25.84210	27.74713	8.91576	39.99482
Sar5.jpg	30.23659	31.71219	10.61032	45.27917
Sar6.jpg	28.57612	30.36024	13.65925	43.09814

Table 3 Entropy values of filtered images

Image name	Original image	Despeckled Image	Median filtering	Wiener filtering	Gaussian filter
Sar1.gif	7.3133	7.0357	6.6986	6.7607	6.9532
Sar2.jpg	7.2411	7.0201	6.8190	6.8539	6.9838
Sar3.jpg	7.2169	7.0310	6.8786	6.9185	7.0063
Sar4.jpg	7.4286	7.2220	6.9700	7.0221	7.1735
Sar5.jpg	7.3272	7.2452	7.1817	7.1980	7.2363
Sar6.jpg	6.7350	6.4440	6.1016	6.1338	6.3838

6. CONCLUSION

In this proposal speckle noise is removed from SAR images using adaptive sigmoid thresholding approach. To enhance the quality of de-speckled image filtering operation is carried out in frequency domain using different filters. Comparative analysis of filtering process is carried out by analyzing the obtained PSNR and entropy values using different filters. Results show that Gaussian filter is giving better results than other filters which are tested for quality enhancement of SAR images. Thus the new proposed algorithm removes the speckle noise and enhances the quality of SAR images as per the implementation results. In future the enhanced image would be used for many applications like object detection, feature extraction etc.

REFERENCES

[1] Johannes R. Sveinsson and Jon Atli Benediktsson, "Speckle Reduction and Enhancement of SAR Images in the Wavelet Domain", IEEE, vol.1, pp.63-66, 1996.

[2] Fabrizio Argenti and Luciano Alparone, "Speckle Removal From SAR Images in the Undecimated Wavelet Domain", IEEE Transactions On Geoscience And Remote Sensing, Vol. 40, No. 11, pp. 2363-2374, 2002.

[3] Alin Achim, Panagiotis Tsakalides, and Anastasios Bezerianos, "SAR Image Denoising via Bayesian Wavelet shrinkage base on heavy tailed modelling", IEEE Transactions On Geoscience And Remote Sensing, Vol. 41, No. 8, pp. 1773-1784, 2003.

[4] Johannes R. Sveinsson and Jon Atli Benediktsson, "Almost Translation Invariant Wavelet Transformations for Speckle Reduction of SAR Images", IEEE Transactions On Geoscience And Remote Sensing, Vol. 41, No. 10, pp. 2404-2408, 2003.

[5] Min Dai, Cheng Peng, Andrew K. Chan and Dmitri Loguinov, "Bayesian Wavelet Shrinkage With Edge Detection for SAR Image Despeckling", IEEE Transactions On Geoscience And Remote Sensing, Vol. 42, No. 8, pp. 1642-1648, 2004.

[6] Dušan Gleich and Mihai Datcu, "Wavelet-Based Despeckling of SAR Images Using Gauss-Markov Random Fields", IEEE Transactions On Geoscience And Remote Sensing, Vol. 45, No. 12, pp. 4127-4143, 2007.

[7] Johannes R. Sveinsson, Magnus Orn Ulfarsson and Jon Atli Benediktsson, "Speckle Reduction Of SAR Images Using Sure-Based Adaptive Sigmoid Thresholding In The Wavelet Domain", in proceedings of Geoscience and Remote Sensing Symposium, pp. IV-462 - IV-465.

[8] Chun-Lin, Liu, "A Tutorial of the Wavelet Transform", February 23, 2010

[9] V. Senthil, R. Bhaskaran, "Robustness Analysis of Blind and Non-Blind Multiple Watermarking using Edge Detection and Wavelet Transforms", in proceedings of 16th International Conference on Advanced Computing and Communications, pp. 106-111, 2008.

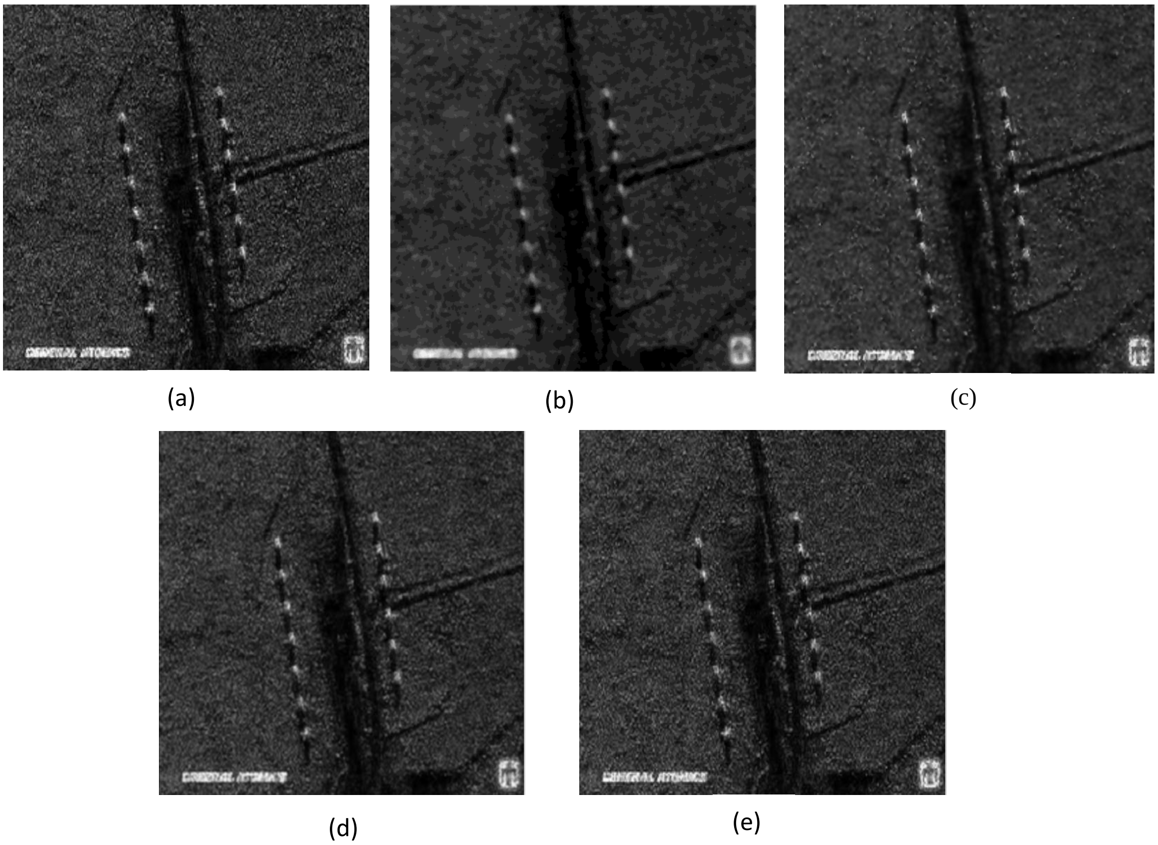

Fig 6 : (a) Input image 'Sar1' (b) Median filter output (c) Wiener filter output (d) Averaging filter output (e) Gaussian Filter output

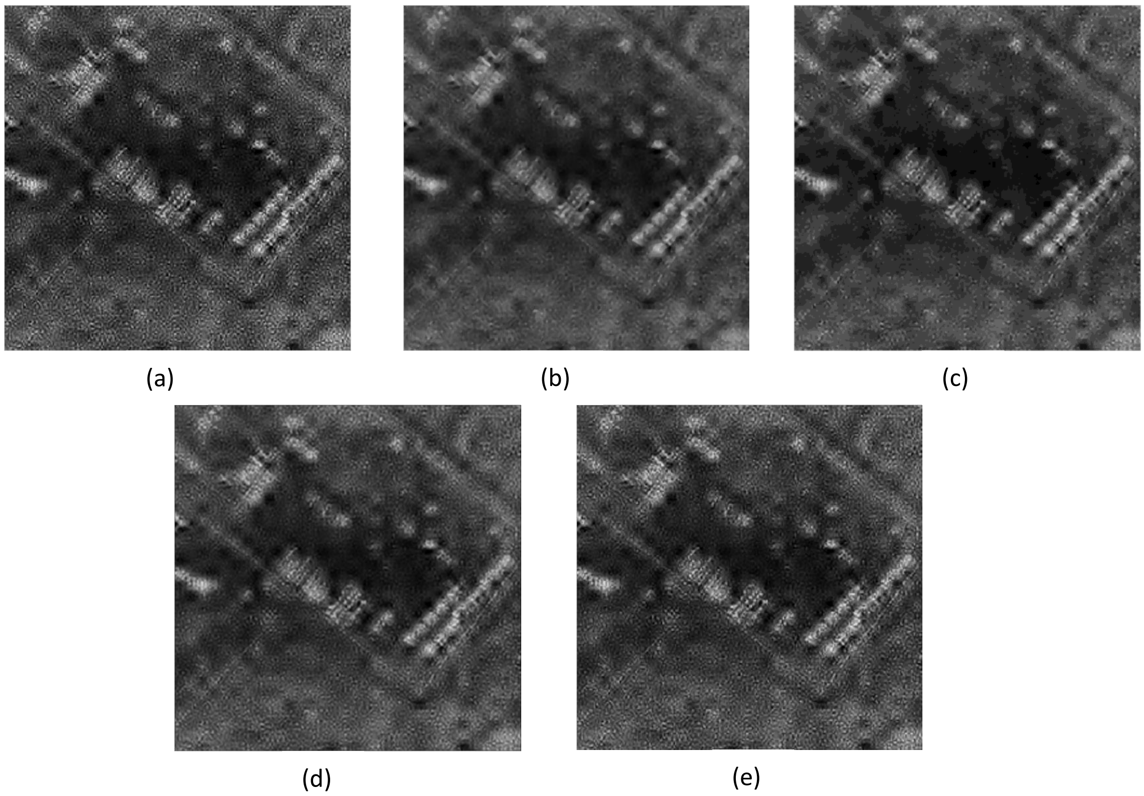

Fig 7 : (a) Input image 'Sar2' (b) Median filter output (c) Wiener filter output (d) Averaging filter output (e) Gaussian Filter output

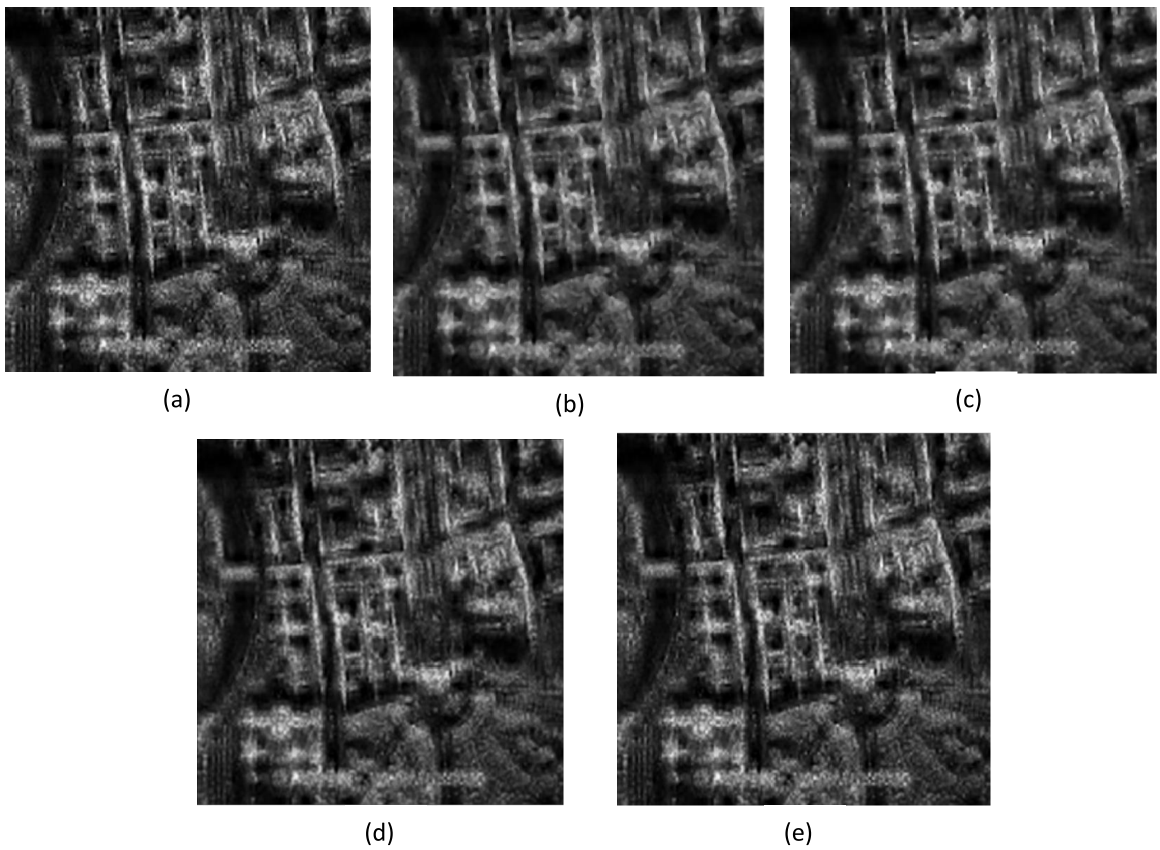

Fig 8 : (a) Input image 'Sar3' (b) Median filter output (c) Wiener filter output (d) Averaging filter output (e) Gaussian Filter output

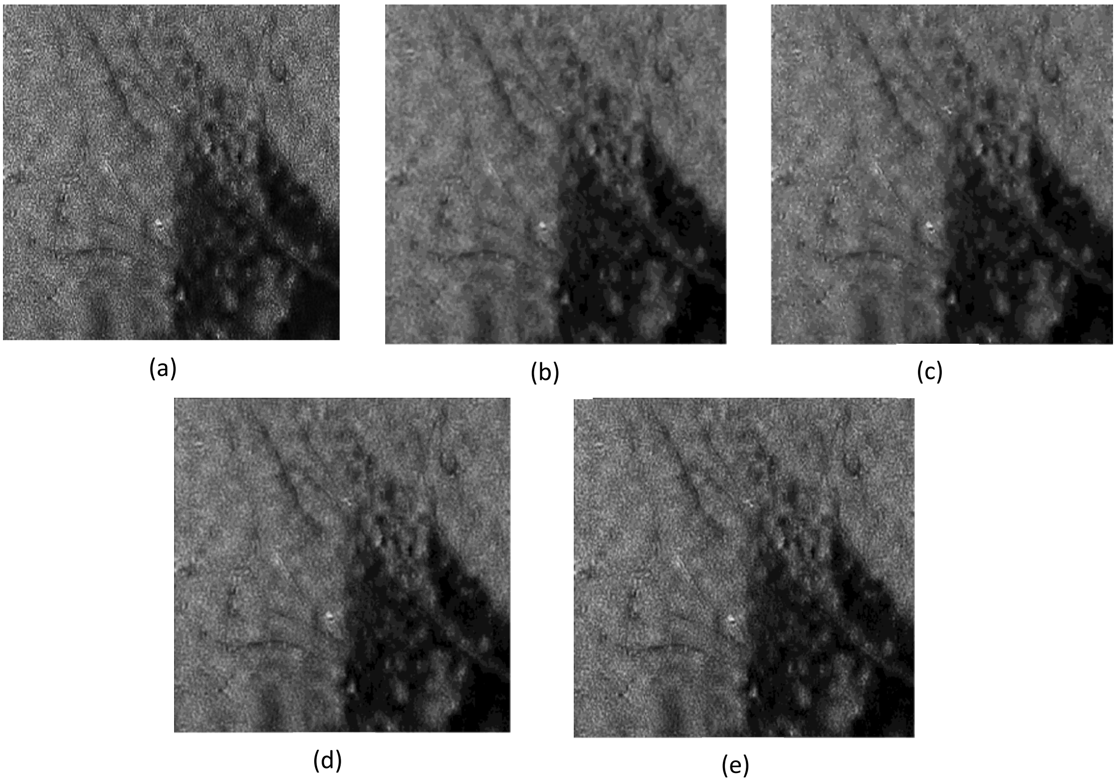

Fig 9 : (a) Input image 'Sar4' (b) Median filter output (c) Wiener filter output (d) Averaging filter output (e) Gaussian Filter output

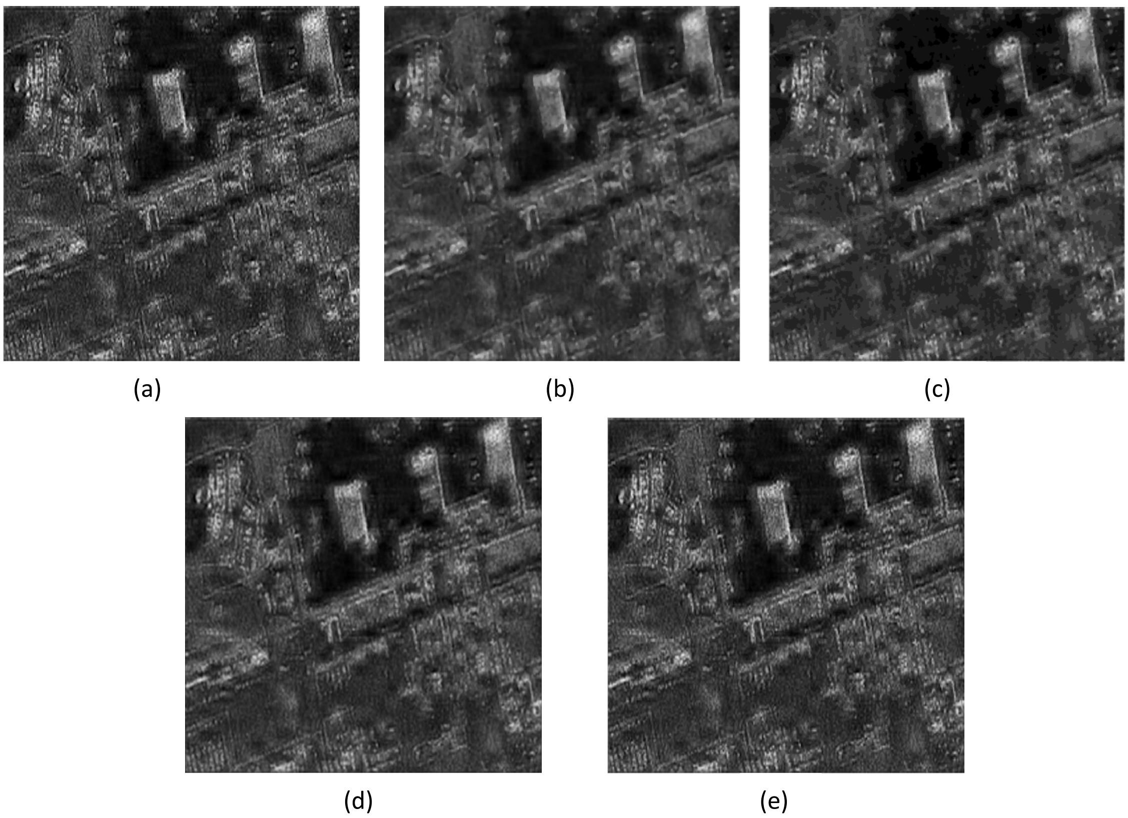

Fig 10 : (a) Input image 'Sar5' (b) Median filter output (c) Wiener filter output (d) Averaging filter output (e) Gaussian Filter output

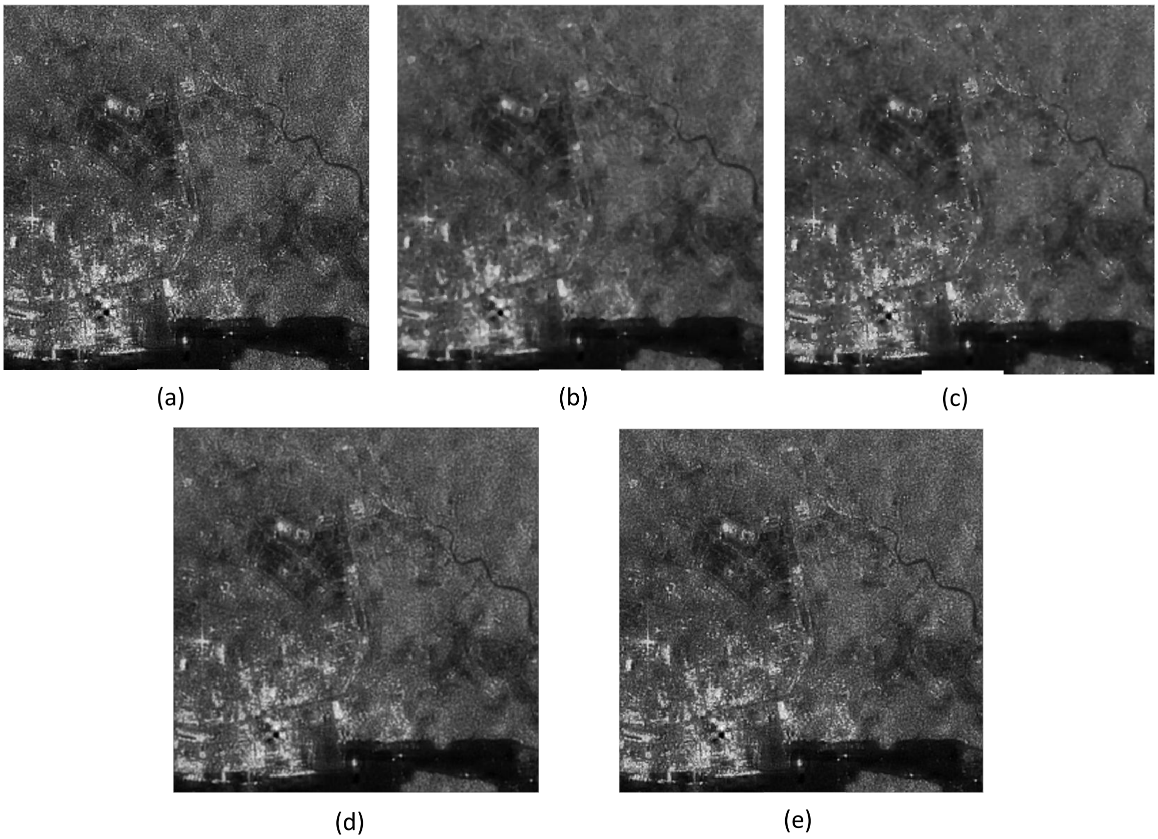

Fig 11 : (a) Input image 'Sar6' (b) Median filter output (c) Wiener filter output (d) Averaging filter output (e) Gaussian Filter output