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Speckle Noise: Modelling and Implementation

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ABSTRACT

Noise in an image plays a vital role in the field of image restoration. There are different kinds of noise that corrupts the images. Reducing noise from the satellite images is one of the major challenge and least touched issue. The kind of granular pattern present in the radar coherent imagesis called as the Speckle noise. Mainly speckle noise is found in the Synthetic Aperture Radar image and airborne images. Speckle noise is a common phenomenon in all coherent imaging systems like laser, acoustic and SAR imagery. Speckle noise is an undesirable effect. The source of this type of noise is caused due to random interference between the coherent returns issued from the so many scatterers present on a earth surface, on the scale of a wavelength of the incident radar wave. Thus reducing such noise from the image is turned out to be a most critical pre-processing step. In general, speckle noise is the grainy salt-and-pepper pattern present in radar imagery, alsospeckle noise can be understood as a granular 'noise' that inherently exists in and degrades the quality of the medical ultrasound, synthetic aperture radar (SAR), active radar and optical coherence tomography images. This paper proposes an detail understanding of speckle noise model with its matlab implementation and imagery analysis.

Keywords: Speckle noise, Synthetic Aperture Radar, Matlab, Histogram.

I. INTRODUCTION

SAR is the form of Radar that is mounted on the satellites and aircrafts that captures the high resolution images of the broad areas of the earth surface.

While capturing such images it has to deal with various weather conditions, day and night, so a special treatment is needed to handle such images because in such case chance of noise intrusion is higher. The kind of noise that attacks in such scenario is called as the Speckle noise.

SAR images are different from optical images. Since SAR images interacts with the ground features in ways different from optical radiation so special care has to be taken when interpreting radar images.While capturing the broad areas of terrain, SAR has to handle the weather condition, day and night.Unlike optical images, SAR images are formed by the coherent interaction of the transmitted microwave with targets (terrain).This coherent interaction causes random constructive and destructive interference resulting in salt and pepper noise throughout the image.

Hence later it suffers from the effects of speckle noise. It is a granular noise that inherently existsin and degrades the quality of the active SAR image. It is a multiplicative noise.

Speckle noise ismultiplicative noise, having a granular pattern it is theinherent property of ultrasound image and SAR image. Another source of reverberationis that a small part of the returning sound pulse may be mirrored back into the tissues by the transducer surface itself, and generates a new echo at twice the depth [1]. The backscattered echoes from irresolvable random tissue in homogeneities in ultrasound imaging

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Figure 1: US Capitol and Library of Congress, Washington, D.C.
(SAR image taken from Sandia National Laboratories.) [8]

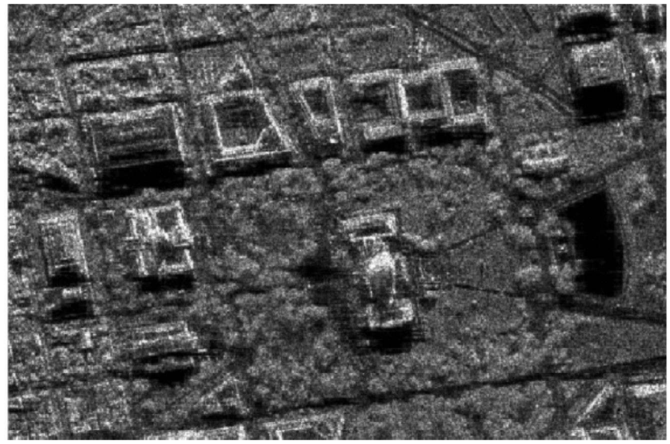


Figure 2: Noisy Image (Speckle Noise=0.2)

and from objects in radar imaging undergo constructive and destructive interferences resulting in mottled b-scan image [1].

Due to wrong assumptions that the ultrasound pulse always travel in a straight line, to and fro from the mirroring interference. Speckle is due to the diffused scattering, which occurs when an ultrasound pulse arbitrarily interferes with the tiny particles or objects on a scale comparable to the sound wavelength. The backscattered echoes from irresolvable random tissue in uniformitiesin ultrasound imaging and sarimaging from objects in undergo constructive and destructive interferences resulting in mottled b-scan image [2, 3]. Ultimately it reduces the performances of important techniques of image processing such as detection, segmentation, enhancement and classification etc. That is why speckle noise should be eliminated before applying any image processing mechanism. There are three main goal of any speckle filtering. First is to eliminate noise in uniform regions. Second is to preserve and enhance edges and image features and third is to provide a better visual appearance. Unfortunately completelyreducing speckle noise isimpossible. Therefore, balance is made among these requirements [4].

This paper composed of four major sections including, Section II describes Speckle noise model which elaborates the mathematical details behind speckle noise. Section III shows the matlab implementation of the addition of speckle noise. Section IV shows analysis of the SAR image and speckled SAR images using histogram plot and last Section V concludes the paper.

II. SPECKLE NOISE MODEL

This noise model depending on signal helps us to smooth the image in the unform regions where the signal is supposed to be constant. Taking the parameter á, the local variance to mean ratio, it is possible to judge whether the improvizedpixel is within the uniform region or not. Usually, if the local variance to the mean ratio is greater than the speckle, thenthat corresponding pixel is considered as a resolvable object. Otherwise it is considered to be in uniform region and is to be subjected to smoothening [1].

Speckle noise is typically modelled as multiplicative noise (Rayleigh noise), therefore resultant signal is the product ofspeckle signal and original noise.

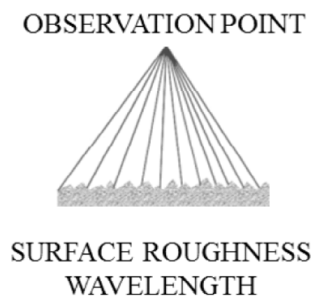
Let I (i, j) is the degraded pixel of an observed image and S (i, j) be the noise-free image pixel which is to be recovered. With the multiplicative noise model,

$$I(i, j) = S(i, j) * N(i, j) \quad [5]$$

In which N (i, j) depicts the multiplicative noise withunit mean and standard deviation [6].

An inherent characteristic of SAR images is the presence of speckle noise. Speckle noise is a random and deterministic in an image. Speckle has negative impact on SAR images. Radical reduction in contrast resolution may be main reason for the poor effective resolution.

Speckle appearing in synthetic aperture radar images is due to the consistentinterference of waves reflected from many elementary scatterers. This produces an effect on pixel-to-pixel variation in intensities, and the variation manifests itself as a granular noise pattern in SAR images. Understanding SAR speckle statistics is essential for good information extraction by developing intelligent algorithms for speckle filtering, geophysical parameter estimation, ground cover classification, etc [9]. When radar throw light on the surface that is rough on the scale of the radar wavelength, the reflected signal consists of waves reverted from many elementary scattererswithin a resolution cell. The distances between the elementary scatterers and the radar receipient vary due to the arbitrarylocation of scatterers. Therefore, the distance from the scatterers to the radar keeps changing. The received waves from each scatterer, although consistent in frequency, are no longer consistentin phase. A powerful signal is received, if wavelets add relatively constructively. A weak signal, if the waves are out of phase[9].



SCATERRING FROM DISTRIBUTED SCATTERERS

↓

COHERENT INTERFERENCES OF WAVES SCATTERED FROM MANY RANDOMLY DISTRIBUTED ELEMENTARY SCATTERERS INSIDE THE RESOLUTION CELL

↓

GRANULAR NOISE

↓

SPECKLE PHENOMENON

Figure 3: Speckle Phenomenon (Origin) [9]

2.1. Single Polarization Multiplicative Speckle Model

Speckle discusses a arbitrary aspect of SAR images, but may not be considered as a simple noise. It is, in fact, related to the SAR measurement principle.

The response of speckle noise is usually represented under the form of a simple product model.

$$y = x * n \tag{1}$$

where y is complex speckled scattering coefficient, x is the original unspeckledscattering coefficient and n isthe multiplicative speckle contribution.The speckle term is made of independent real and imaginary parts following both real centered Normal distribution $N_c(0,1/2)$.

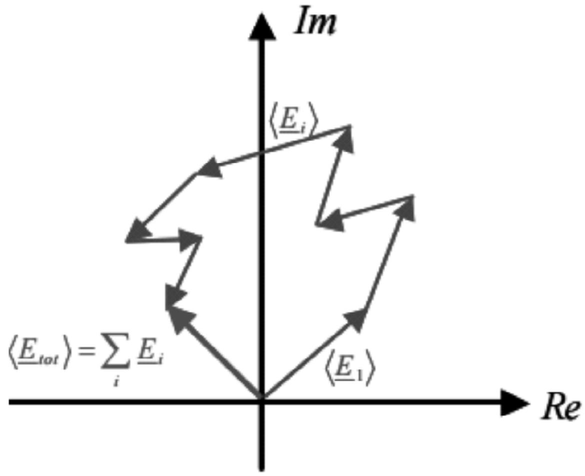


Figure 4: Principle of coherent integration [11]

The corresponding speckled intensity, Y, is

$$Y = yy^* = xx^* \, nn^*$$
$$Y = X \, nn^* \tag{2}$$

Over uniform areas X is considered to be constant and the speckled intensity follows an exponential PDF

$$P(Y) = X^{-1} \, e^{Y/X} \tag{3}$$

Its first two moments are given by

$$E(Y) = X \, E(nn^*) = X$$
$$Var(Y) = X^2 Var(nn^*) = X^2 \tag{4}$$

2.2. Polarimetric Multiplicative Speckle Model

This speckle noise model may be extended to the polarimetric case by considering that polarimetric channels are affected by independent multiplicative speckle components:

$$\begin{bmatrix} S_{11} \\ S_{12} \\ S_{22} \end{bmatrix} = \begin{bmatrix} x_{11} & & \\ & x_{12} & \\ & & x_{22} \end{bmatrix} \begin{bmatrix} n_{11} \\ n_{12} \\ n_{22} \end{bmatrix} \Rightarrow \begin{bmatrix} |S_{11}|^2 \\ |S_{12}|^2 \\ |S_{22}|^2 \end{bmatrix} = \begin{bmatrix} X_{11}(n_{11}n_{11}^*) \\ X_{12}(n_{12}n_{12}^*) \\ X_{22}(n_{22}n_{22}^*) \end{bmatrix}$$

III. IMPLEMENTATION

Speckle noise can be modelled by pixel values multiplied by random values; hence it is called multiplicative noise. Speckle noise is a big problem in some radar applications. Removing the Speckle noise from the satellite image is one issue for the researchers but before that, it is needed that, how to add speckle noise into the image which comes before the pre-processing and stills an issue for the new researchers.

In terms of practical implementation of adding the speckle noise in the image can be performed in two ways in matlab. Firstly there is matlab inbuilt command function where the value is given to speckle noise in the source script matlab file. It is static method. Another method is to program a function for adding speckle noise in the image whose value is decided by the user at the running phase. It is dynamic method.

3.1. Matlab Inbuilt Command

imnoise() is the function which is used to add noise to image.

J = imnoise(I,type) adds noise of a given type to the intensity image I. type is a string that specifies the types of noise [7].

J = imnoise(I,'speckle',s) adds specklenoise to the image I, using the equation

$$J = I+n*I,$$

where n is uniformly distributed random noise with mean 0 and variance s. The default value of s is 0.04 [7]. The value of s ranges from 0 to 1. 0 means no noise and 1 means 100% noisy image.The mean and variance parameters for 'gaussian', 'speckle', and 'localvar' noise types are always specified as if the image were of class double in the range(0, 1) [7].

Code:

```
i=imread('Sandia mini SAR image.jpg');
j=rgb2gray(i)
k = imnoise(j,'speckle',0.6)
subplot(2,2,1);
imshow(j);
title('Original Image');
subplot(2,2,2);
imshow(k);
title('Speckled Image');
```

Output

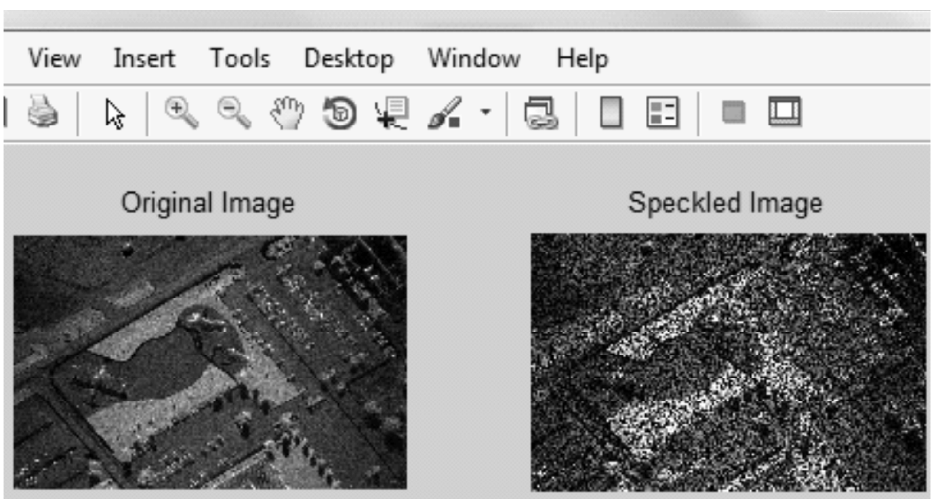


Figure 5: Snapshot of Output (60% noise added)

3.2. Manual Method Using Matlab Programming

Algorithm

i. Input image = SAR image.

ii. Preprocessing: Checking RGB image

if(input image = RGB image)

Convert RGB image to Grayscale image

Convert resultant image to double precision(I) else

Convert Grayscale image to double precision(I)

iii. Add speckle noise(s), by entering variance of the speckle noise to the I image, using AddSpecNoise() function file.

iv. if(no. of input argument in function<2)

s = 0.04;

end;

if(no. of input argument in function<1)

Error: SAR image Missing;

End;

v. Add multiplicative noise, s to the image, I using *imnoise(I,'speckle',s)* function.

vi. Final output image = Speckled noise.

In manual method to program, two functions are created one for pre-processing, to check whether the input image is grayscale or not and another function is created to add speckle noise into the image. A main source script program will access these two functions and finally add the noise in the image using value entered by the user during execution phase (Majorly SAR images are processed as grayscale images, so this above algorithm is dedicated to only grayscale images).

Analyze.m is the main source script file that access the two functions i.e.preprocess.m and AddSpecNoise.m to add the noise in the image. Analyze.m script is executed. During execution, it asks for the image. As provided it pre-processes the image and then add the multiplicative noise to the image I using the equation,

$$J = I + n * I$$

where n is uniformly distributed random noise with mean 0 and variance s. The default for s is 0.04.

Output 1

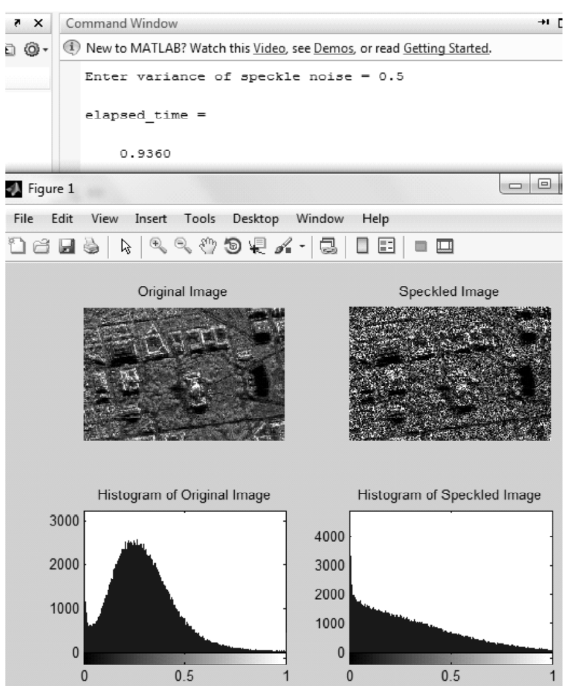


Figure 6: Snapshot of the output (50% Noise added to the image Figure 1.) (Original Image and Speckled images with their pixel intensity distribution)

In above Figureure multiplicative noise is added to the Figure 1. image using the variance of 0.5 i.e. 50% noise added at the execution phase of the program. Histogram of the original image and speckled image depicts the pixel intensity distribution.

Output 2

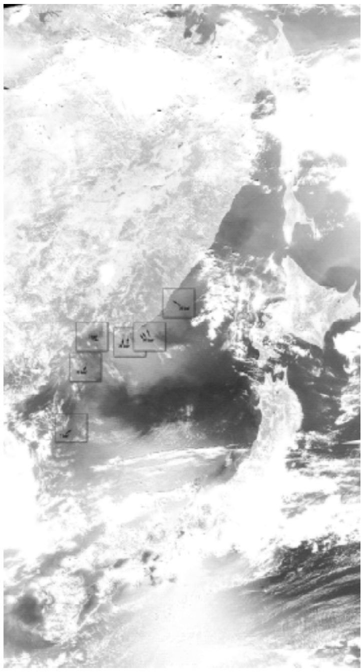


Figure 7: OriginalSAR Image [10]

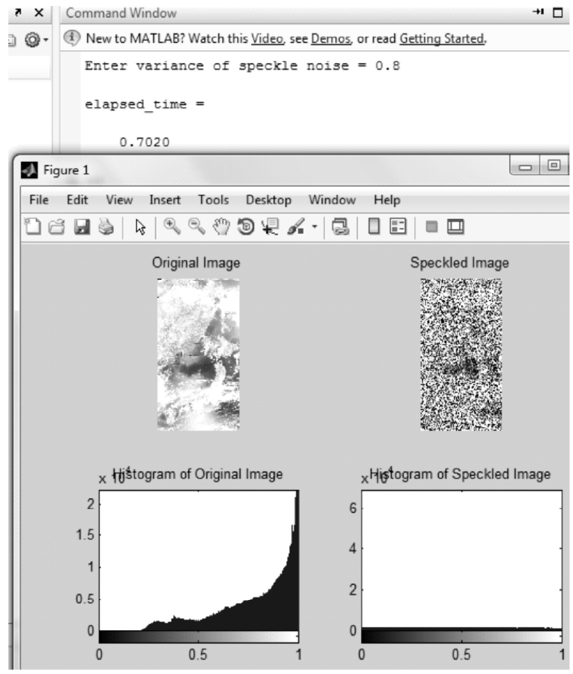


Figure 8: Snapshot of the output (80% noise added to the image Figure 7.) (Original Image and Speckled images with their pixel intensity distribution)

Since the algorithm is dedicated to only grayscale images, so first of all, the original colored SAR image Figure 7. is converted to grayscaleimage (pre-processing) and then after the rest operation is performed.

Output 3

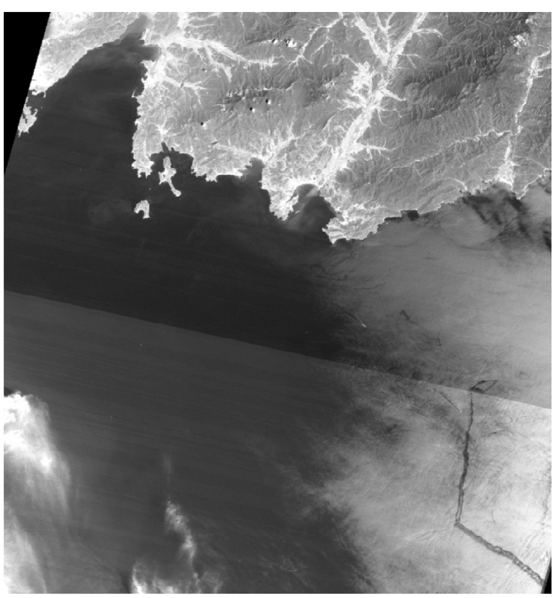


Figure 9: Original Image [10]

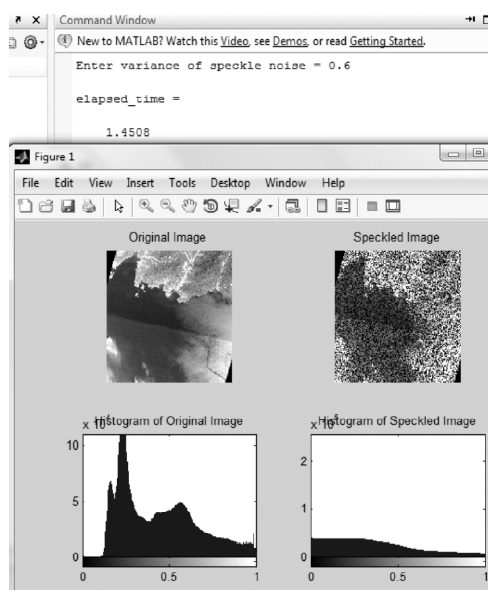


Figure 10: Snapshot of the output (60% noise added to the image Figure 9.) (Original Image and Speckled images with their pixel intensity distribution)

IV. ANALYSIS

Figure11: Original Image [8]

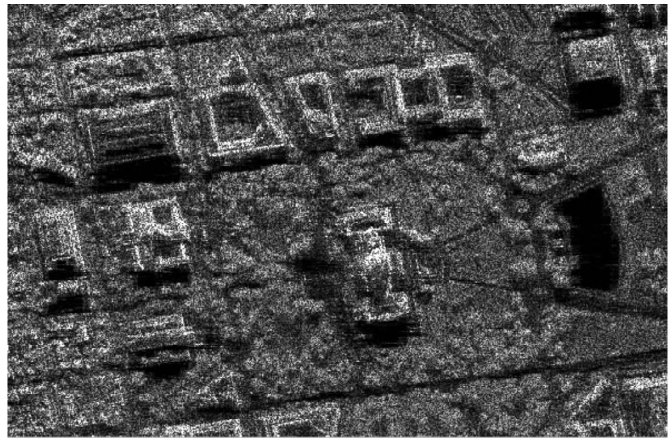


Figure12: Speckled Image (20% Noise)

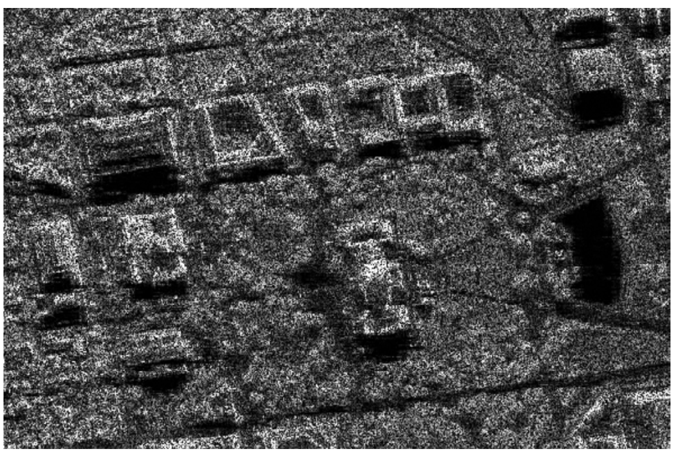


Figure13: Speckled Image (50% Noise)

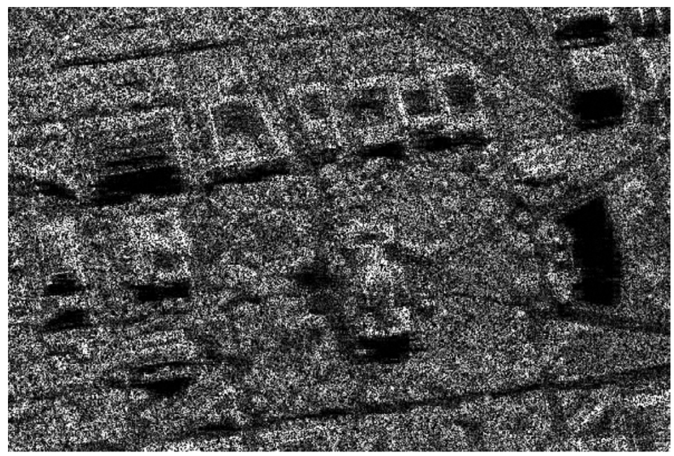


Figure 14: Speckled Image (90% Noise)

Figure 15: Speckled Image (20% Noise)
(Figure 7. is Original image)

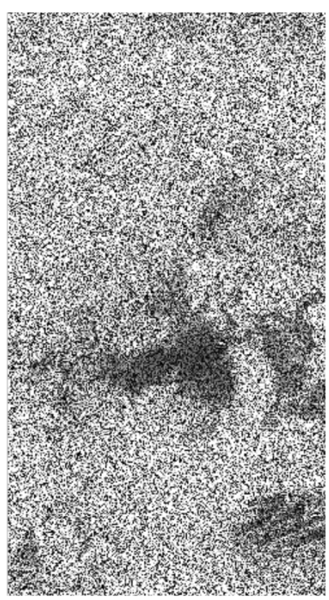


Figure 16: Speckled Image (50% Noise)
(Figure 7. is Original image)

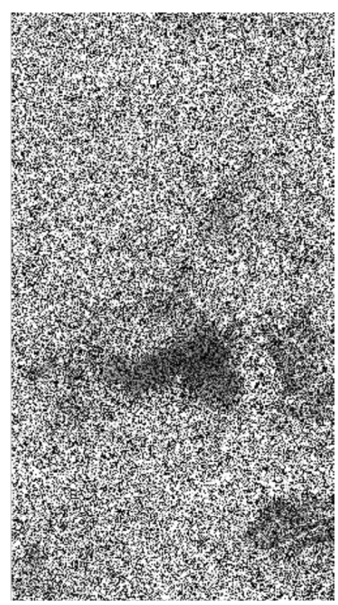


Figure 17: Speckled Image (90% Noise)
(Figure7. is Original image)

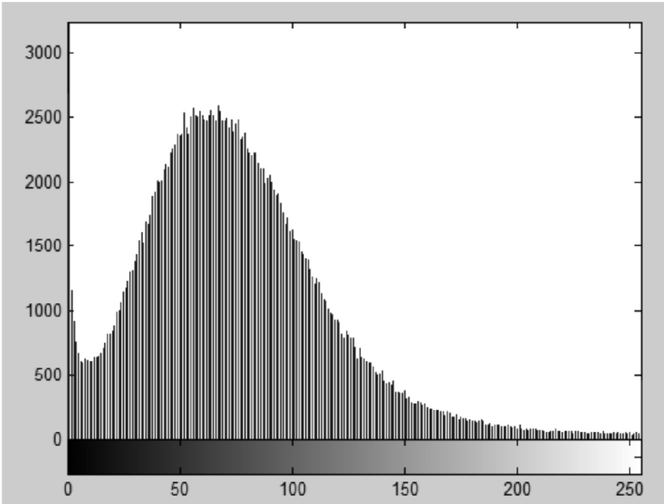


Figure18: Pixel intensity distribution of Figure 11 (Original Image)

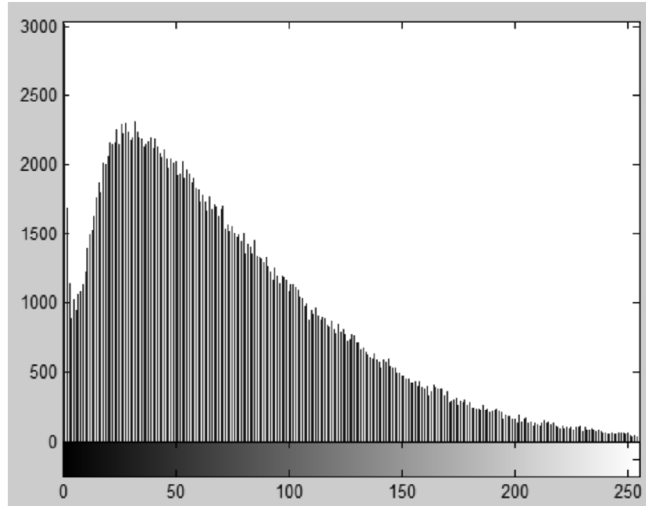


Figure 19: Pixel intensity distribution of Figure12 (20% Noise)

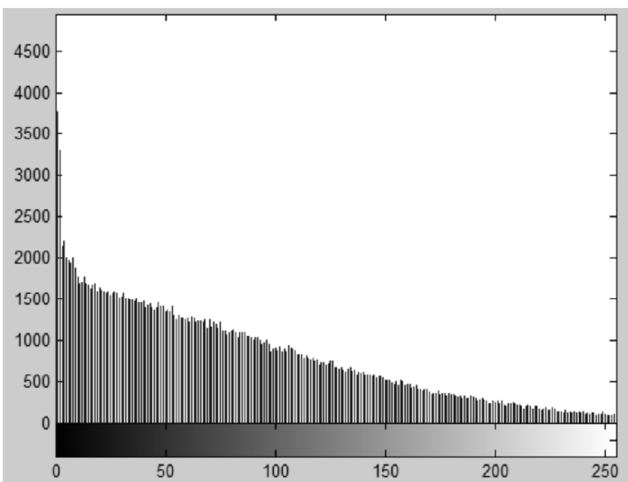


Figure20: Pixel intensity distribution of Figure13 (50% Noise)

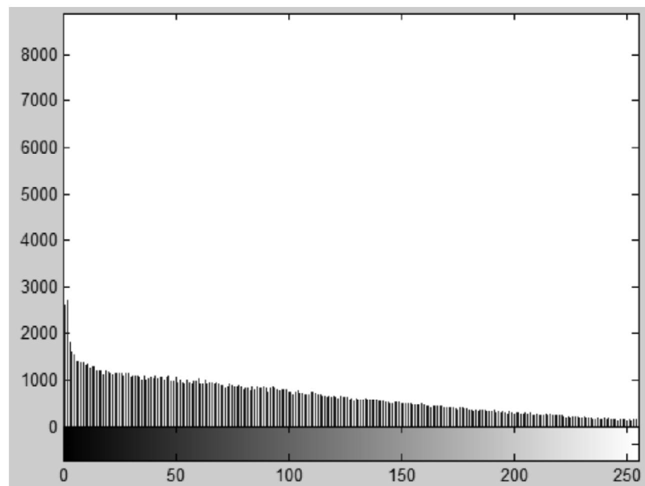


Figure21: Pixel intensity distribution of Figure14 (90% Noise)

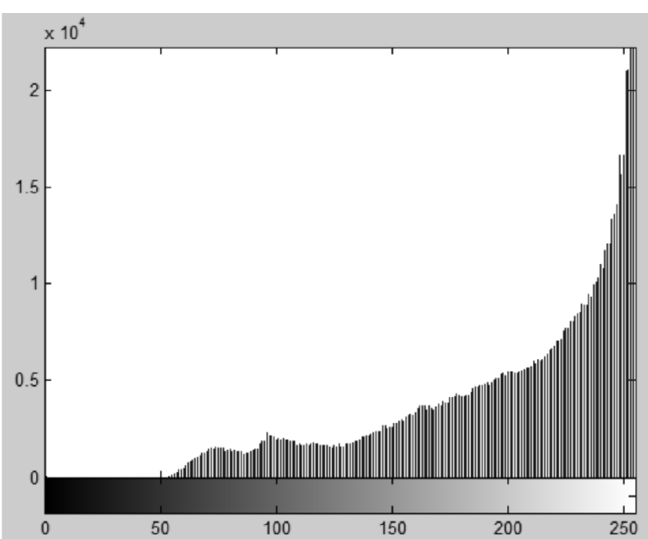


Figure22: Pixel intensity distribution of pre-processed form of original image,Figure 7

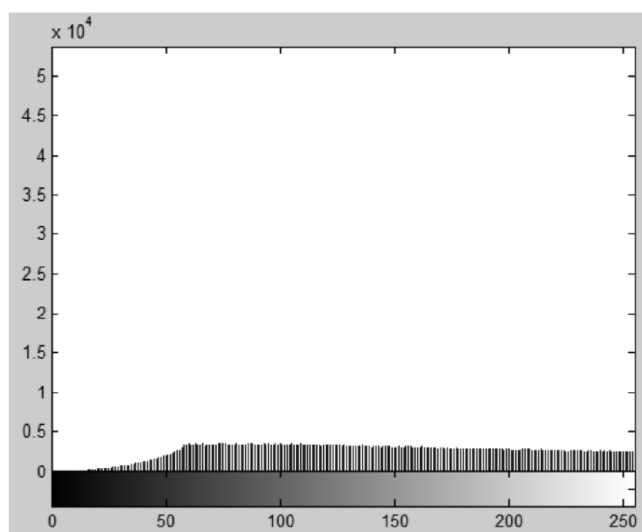


Figure23: Pixel intensity distribution of Figure 15 (20% Noise)

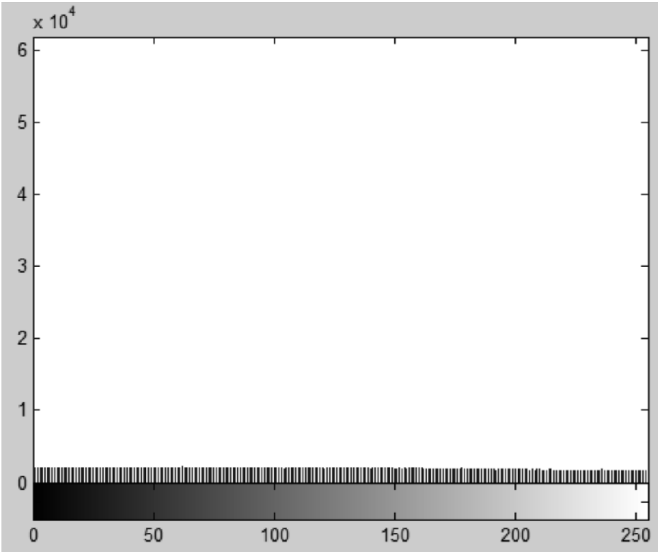


Figure 24: Pixel intensity distribution of Figure 16 (50% Noise)

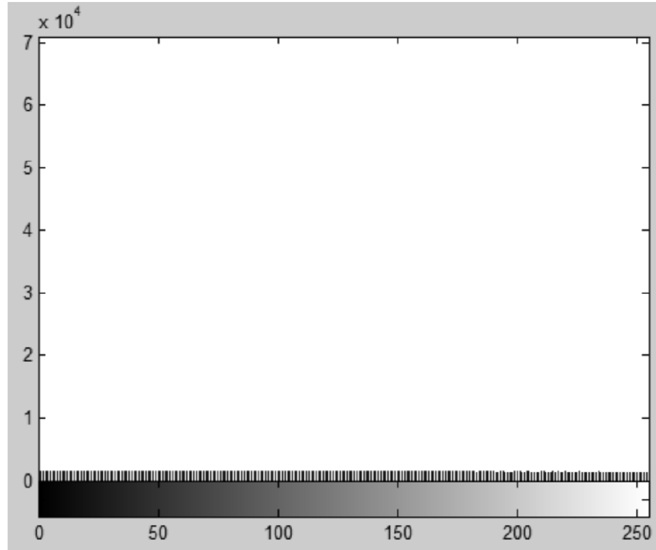


Figure 25: Pixel intensity distribution of Figure 17 (90% Noise)

In the Figure 11, 12, 13, and 14, it can be seen by the observation that as the variance of the speckle noise is increasing the degradation is also increasing as the objects in the image are non-recognisable due to the increase of grain like structure noise. By increasing the speckle noise in the image, the actual changes can be analysed and studied by the plotting the histograms. Figure18, 19, 20, and 21 depicts the histogram of the original image and noisy images.

Figure 18 shows the histogram of the original image that depicts that in the original image maximum number of the pixels of the image is lying in the approximate range of 45 to 100 intensity value. But as we see in the further histograms that, as the noise is increased in the image, slowly and steadily the histogram is equalizing and that means that in the case of 100% noise there will be each and every intensity value ranging from 0 to 255 will have same number of the pixels that does not mean that histogram equalization will be achieved but the only the canvas resolution of the image will be left. Rest everything (foreground and background) will be distorted and destroyed.

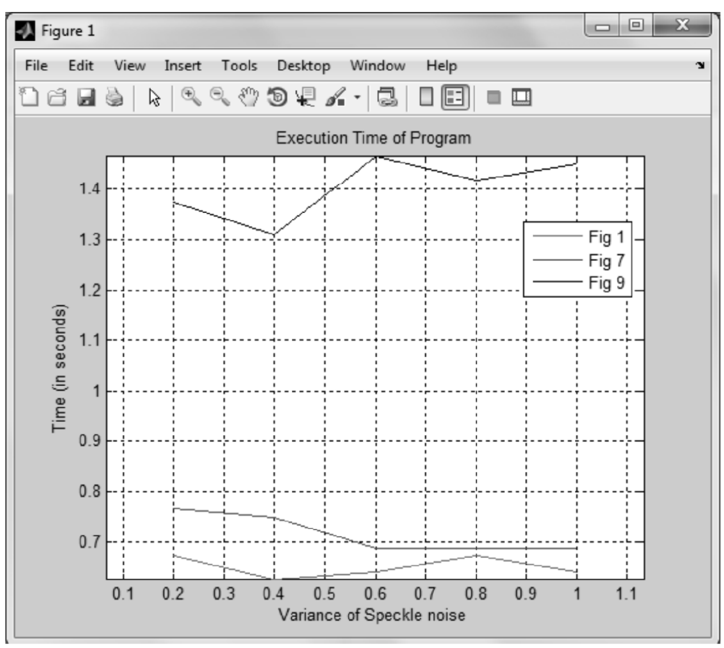


Figure 26: Execution time of the program

Above plot depicts the time taken by the image to the addition of the speckle noise. A pository analysis is being made on the developed algorithm, so the time required on adding the speckle noise in the SAR image is machine dependent. So the above execution time is obtained under following system requirements:

Windows 7 Operating System Home Premium 64-bit with installed memory(RAM) of 4 GB and Processor of Intel(R) Core(TM) i5-2410M CPU @ 2.30GHz.

In the evaluation of the execution time, apart from system requirement the role of the computational requirement is also very high. Let say an image of size 1024*1024 will take more time to process as comparison to image of size 256*256.

1024*1024 pixels ==> 2^20 (~10^6) = 1 Mbytes. Suppose each and every pixel must be treated once, using a computer system with speed = 10^(-8) sec/operation, it takes 10 ms to process 2^20 pixels. In real time, we are required to process 60-85 frames/sec (1 frame in 12-16 ms). Typically, there aremany high-complexity operations must be performed on the image. Therefore, computational requirements are very high and often special purpose hardware is used.

V. CONCLUSION

Since Radar images are formed by coherent interaction of the transmitted microwave with the targets. So it suffers from the adverse effects of speckle noise which arises from consistentsummationof the signals from ground scatterers loosly distributed randomly within each pixel. ASAR image appears noisier than an optical image. Reducing speckle noise completely from the noisy image is an impossible task and as the noise part increases, the probability to achieve the original image also decreases. This specially occurs in the case of the speckle noise.The intensity of each and everypixel represents the microwave backscattered relative to that area on the ground which depends on a variety of factors:shapes, sizes, typesand orientations of the scatterers in the target area; moisture content of the target area;polarisation and frequencyof the radar pulses; as well as the incident angles of the radar beam.This paper describes the complete understanding of speckle noise including its mathematical details and also describes the practical implementation of the addition of the speckle noise in the image using matlab programming including static and dynamic approaches and finally analyses the output results through histogram plotting. This paper will be very helpful for the new researchers who are interested to work in the field of the radar images.

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