Journal of Medical Systems (2019) 43: 222
https://doi.org/10.1007/s10916-019-1299-0

TRANSACTIONAL PROCESSING SYSTEMS

Hybrid Laplacian Gaussian Based Speckle Removal in SAR Image Processing

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Received: 7 January 2019 / Accepted: 17 April 2019 / Published online: 11 June 2019

Abstract
Synthetic Aperture Radar (SAR) images are plays a significant role in different application fields like airborne, civilian and to observe various scenarios over the horizon. Unfortunately, SAR images are heavily affected by speckle noise. The speckle degrades the image quality which makes interpretation of images harder. Therefore suppression of speckle is important for further processing. In this paper a new method is proposed for despeckling of SAR image comprises of two stages. First stage is despeckling process which is based on directional smoothing and hard thresholding technique and second stage is image enhancement process which is based on applying HLGF filter. The proposed work has been tested on and show remarkable performance over the existing system. The simulation results confirmed that achieving a better Peak Signal to Noise Ratio (PSNR), Speckle Suppression Index (SSI) compared with existing method.

Keywords Speckle reduction · Synthetic aperture radar (SAR) image · Directional smoothing hybrid laplacian gaussian filter (HLGF) · Dehazing algorithm · PSNR · SSI and SMPI

Introduction

Synthetic Aperture Radar (SAR) is a special type of radar that is closely connected to many satellites and aircraft system which captures images as in high resolution from the large surface area of the earth. It is one of the important technologies for several real time applications such as Earth surface monitoring, geo-hazard investigation, military surveillance, forestry, terrain discrimination, global change and etc. However, unfortunately due to its imaging mechanism, it suffers from speckles which degrades the visual quality of images for interpretation and hinder when image processing tools extracting image information. Therefore, despeckling is an imperative problem in SAR image processing. Speckle reduction usually consists of three stages. First stage is to transform a noisy image to frequency domain. The second stage is the manipulation of coefficients. The third stage is to transform the resultant coefficients to the spatial domain.

There are several algorithms and techniques have been developed for effectively remove speckle noise from SAR images. Traditionally, there are two despeckling methods were used. One is multi-looking processing, which particularly took incoherent addition of many independent images of multiple scans of the terrain. The disadvantage of this method is which degrades the image resolution. The second method is conventional filtering technique such as median filter, weighted median filter, kuan filter, moving average filter and so on designed for removing speckle noise. These adaptive filters are very simple and more efficient, however this methods are not able to preserve image properties like sharpness, intensity, edge, boundaries,etc.

In recent years wavelet based speckle reduction is becoming field of interest as the noise present in the sub bands are in small coefficients and details are present in larger coefficients. Earlier researchers use Discrete wavelet transforms (DWT) technique to suppress speckle noise from radar images. But, major disadvantage of DWT is that some of important image coefficients may loss during transformation process. In order to mitigate this issue, other technique known as Non-

This article is part of the Topical Collection on *Transactional Processing Systems*

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Decimated Wavelet Transform (NDWT) performed for speckle suppression. The key operation is to fill the intermediate gaps between decimation steps in DWT, which leads to redundant and over representation of decimated original data. It is ensuring that in above mentioned two techniques DWT and NDWT selecting an optimum thresholding value is an important task.

There are several algorithms and techniques have been developed for effectively remove speckle noise from SAR images. Traditionally, there are two despeckling methods were used. One is multi-looking processing, which particularly took incoherent addition of many independent images of multiple scans of the terrain. Since the image resolution has been degraded in this method. The second method is conventional filtering technique such as median filter, weighted median filter, kuan filter, moving average filter and so on designed for removing speckle noise. These adaptive filters are very simple and more efficient, however they are not able to preserve image properties like sharpness, intensity, edge, boundaries and etc. and depending upon the terrain of interest, their performance efficiency also varied. Except from these common methods, discrete wavelet transforms (DWT) is an another technique to suppress speckle noise from radar images. But, major disadvantage is some of important image coefficients may loss during transformation process. In order to mitigate this issue, other technique known as non-decimated wavelet transform (NDWT) performed for speckle component suppression. The key operation is to fill the intermediate gaps between decimation stpes in DWT, which leads to redundant and over representation of decimated original data. It is ensuring that above mentioned two techniques must selecting an optimum thresholding value is important task. Various thresholding methods were proposed such as soft, hard, sure shrink, bayes shrink, oracle shrink, neural network thresholding and so on. Each of having its own merits and demerits, among them hard thresholding is considered as superior one compared to others. By considering several methods limitations research work propose Hybrid Laplacian Gaussian Filter (HLGF) based speckle suppression, through hard thresholding based speckle suppression to obtain high resolution SAR images. The proposed approach is a hybrid technique based on HLGF filter to effectively despeckling the SAR image. It can be well suited and applied in real world imaging applications.

Many thresholding methods were proposed such as soft, hard, sure shrink, bayes shrink, oracle shrink, neural network thresholding and so on. Each of having its own merits and demerits. Thus we are using a Hybrid Laplacian Gaussian Filter (HLGF) based speckle suppression technique through directional smoothing and hard thresholding. The proposed approach is a hybrid technique which effectively suppress speckle in SAR image. The proposed method gives best results as compared with others.

Related works

The Relevant information related to our proposed research is discussed in detail in this section. The appropriate removal of Speckle noise in Synthetic Aperture Radar (SAR) is a high priority one in certain predominant applications like airborne, space and military purposes. Hence, an efficient approach is necessary to govern this problem [1]. One of the inherent issues in Synthetic Aperture Radar (SAR) is occurrence of speckle noise. Conservation of important characteristics of SAR images like pixel-point, perfect structure and texture features are must involved several estimation process that adapts in any critical environment. Conventionally, the non-local approaches provides pliable framework to preserving resolution of the images. Deledalle [2] et al. outline, a general approach called NL-SAR which makes enhanced non-local neighborhood characteristics for denoising, polarimetric and interference-less SAR images. The neighborhood characteristics are taken on the basis of pixel similarity between adjacent pixels that done by channel comparison of image patch. The followed proposed system automatically handles either single and multi-looking SAR image which may or not having interferometric or polarimetric channels. Loizou [3] et al. had presented a new mechanism, software toolbox which is operated as an integration of despeckling filter characteristics from ultrasound images for common carotid artery analysis. In order to improve performance of software toolbox system, we use ten familiar techniques with 100 ultrasound images. From the input ultrasound images up to sixty five varieties of extracted feature sets are derived for analysis.

The improved fast adaptive non-local based removal of SAR despeckling algorithm is presented in the paper [4]. A novel homomorphic SAR despeckling method that is implemented in directionlet domain and performs homomorphic transformation is suggested in the paper [5]. To build a noise free SAR images by using Bayesian technique that takes directionlet coefficients of Laplacian mixture PDF with zero-mean. The Laplace Mixture Model (LMM) incorporates spatial mutual information in the directionlet domain. Gragnaniello [6] et al. had proposed a new approach for reduction of speckle noise in Synthetic Aperture Radar (SAR) that comprises several combinations of multiple input image data and it should be involved in alternate estimators to increase performance of despeckling. In this proposed approach, they follow soft classification and two state - of -the-art experimental tools with complementary properties of effectiveness of estimators. The Performance assessment of preferred objective is a main key influence factor for constructing effective image processing algorithms in real world. In Synthetic Aperture Radar (SAR), due to lacking of speckle free SAR images are precludes by reliable full reference data measurement. In recent years, Performance assessment methods are carried out by either visual inspection or simulated based optical images, however both are built for different situational environment.

Martino [7] et al. had constructed an innovative framework predominantly for quantitative (objective) assessment of different SAR despeckling techniques which depends upon relevant canonical scenes. All input SAR images are having proper sensed surface area, scattering properties and individual operating mode. The different SAR images are taken at different instance of controllable parameters and object reference assessment method considers both speckle suppression and feature preservation. The reduction of Speckle noise in Synthetic Aperture Radar (SAR) is a pre-requisite one for many digital image processing applications. Sadreazami [8] et al. had presented a Contourlet domain based despeckling of SAR images which uses alpha-distribution algorithm that gives portable values of countourlet coefficients for an input image. After that constructed research model is exploited in a Bayesian maximum a posterior estimator that restores which image has noise-free contourlet coefficients. The symmetric property of alpha-stable distribution algorithm is represented in logarithmic form. Choi [9] et al. had presented a new method, speckle reduction anisotropic diffusion algorithm that utilizes soft thresholding concept with a guided filter in order to effectively remove the speckle noise while maintaining sufficient image features. The additional noise can be removed by applying discrete wavelet transform, the soft thresholding and guided filter used to analyze both the high frequency and low frequency sub images.

Glaister [10] et al. had suggested a novel stochastic texture based approach that suppresses speckle noise while keeping detail information about structural and texture features of the images. The estimation of true signal is done by two algorithm namely Local texture model and a Fisher-Trippett logarithmic-space speckle distribution model. In addition to Monte Carlo texture sampling strategy that permits speckle statistics and texture characteristics. Through simulation result, they confirm that the proposed approach has strong capability of speckle noise elimination compared to other despeckling algorithms. In the paper [11] et al. suggested a new approach for noise removal in SAR images which is based on sparse reconstruction coding that performs shear-lets filtering technique. In their research, they used shear let transformation technique to evaluate effective strength of speckling noises. Gokul [12] et al. had introduced a improved method for Generalized guided filter with Bayesian non-local information that incorporates dynamic parametric constant which is depends on heuristics from image statistics for weighted computation.

In the paper [14] a fourth order diffusion filtering method to suppress characteristics of speckle noise from the input images. Savithri [13] et al. had proposed an alternate method for SAR image despeckling which uses bandlet transform with firefly algorithm. Initially, this algorithm is carried out shrinking and stretching with coefficients of bandlet transform of SAR image. The overall image quality is improved, performing image enhancement as an integration of crucial features. Additionally, the superior parameters are governed from despeckled image by applying evolutionary algorithm called Firefly algorithm which performs continuous wavelet transform. Sumaiya [15] et al. had revealed a Dual tree complex wavelet transform based Bayesian approach in order to despeckling the noise in SAR images. The reflecting noises in each sub-band are continuously transformed into wavelet coefficients by using heavy-tailed Burro algorithm with Gaussian distribution functions. Most of the Filtering techniques are developed based on the theory of wavelet, anisotropic diffusion, an initial statistical information and single or multi resolution non-local information. Birader [16] et al. had investigated the several kinds of filtering mechanisms in order to solve noise problems in despeckling applications.

Nisha Devi [17] et al. had reviewed all features of SAR images and different resolution techniques are used to solve the speckle noise. After analyzing several despeckling techniques strength and weakness they had chosen the best one for their study. Their proposed system is involving the fundamental image processing steps such as preprocessing, feature extraction, segmentation and then classification. Jidesh [18] el al had proposed an improved Mumford-Shah level-set model that handles speckles and blurring problems in Synthetic Aperture Radar Imagery. The proposed scheme based on non-local regularization framework and take gradient oscillations during speckle intensity evaluation process. For iteration, regularization parameter is estimated by using maximum likelihood estimator. Split-Bregman iterative estimation scheme is used to increase convergence rate of proposed model and finally Statistical quantifiers are used to calculate precise numerical value of proposed scheme. In the paper [19], Singh et al. presented a 2D-DWT for denoising SAR image by applying both soft and hard thresholding technique using haar wavelet coefficients. Jidesh [20] et al. had introduced a Non-local Total Bounded variation reputational model that having capability of restoring which image is corrupted and related with its speckles and linear blurring artifacts. This model is mainly employed to restore speckled and blurred images of Ultrasound (US) and Synthetic Aperture Radar (SAR) images. Several approaches are developed in order to suppress Speckling noise namely single looking, multi-looking, wavelet-based, filtering methods and block matching. It is important to note that these approaches are using homomorphic filtering process, which transforms multiplicative noise into additive noise is done by taking logarithm of input data. Since, these approaches having weakness that is it introduces biasing in denoised images. Although, it is fail to conserve the sharp features of SAR images.

Basic principal of speckle theory and filtering technique

Speckle noise model

Image despeckling is important in SAR as they suffer from speckle noise. To overcome this problem directional smoothing using hard thresholding was proposed.

The generalized model of the speckle noise in SAR image is denoted as

$$g(m,n) = f(m,n)*u(n,m) + \xi(n,m) \tag{1}$$

Where, g(m,n) is observed image, f(n,m) is original image, u(n,m) is speckled noise, and ξ (n,m) represents additive component of speckle noise. The variables n and m denotes axial and lateral of image samples.

Noise in SAR (synthetic apertures radar) images

Synthetic Aperture Radar (SAR) is a popular technique since it can be applied in different applications. In SAR image processing, speckled noise D (i.j) is modeled as the product of two components; one is noise-free SAR I (i,j) image and another is speckled noise M (i,j).

$$D(i,j) = I(i,j)*M(i,j) \tag{2}$$

Where D (i,j) is the observed image, I(i,j) represents original SAR image and M(i,j) is speckled noise whereas i and j are indices of spatial location coefficients.

Speckle filtering techniques

The denoising and enhancement process of a Synthetic Aperture Radar (SAR) images are major challenging task in image analysis. It involves two phases as pre-processing and post phase for the suppression of Speckle in SAR image and enhancement of SAR images respectively.

Preprocessing phase

In this phase for the input SAR image we first apply a filter called Directional smoothing and we adopt a hard thresholding method to find the optimum threshold value which is very essential to suppress the speckle in SAR images. Now the output i.e. Despeckled SAR image is given as input to the second phase.

Post processing phase

After preprocessing phase is over i.e. after getting despeckled SAR image image, we approach the second phase in order to do enhancement in the output image which is effectively carried out by using that Hybrid Laplacian Gaussian Filtering (HLGF) by implementing Dehazing algorithm.

From the above Fig. 1 the proposed method is represented as flow sketch. Initially read the SAR image and then add the noise to SAR images. The proceed with preprocessing phases like directional smoothing, and hard threshold is applied in this method. After preprocessing and post processing is applied where the HLGF is applied with dehazing algorithm, finally we get despeckled and enhanced SAR image is obtained.

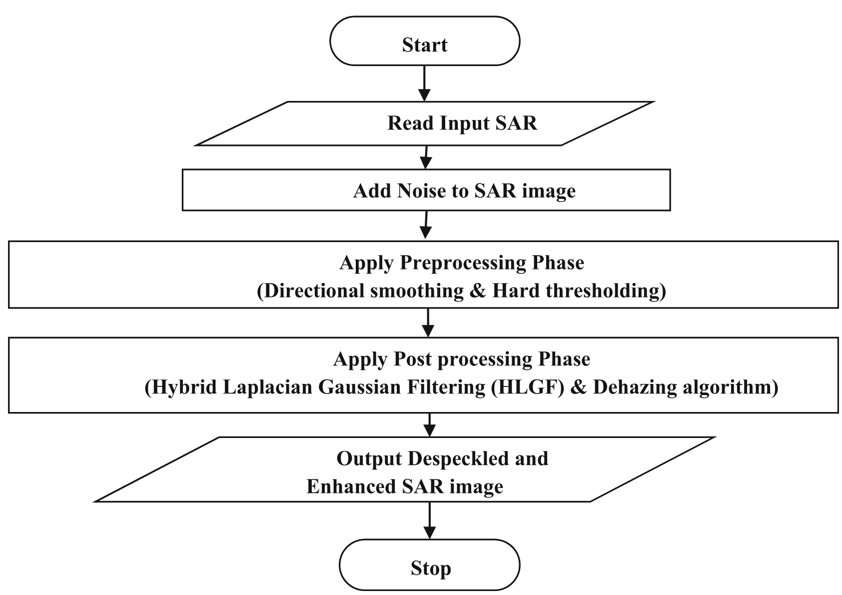

Fig. 1 Flowchart of Proposed Method

Proposed methodology

Image despeckling is important in SAR as they are innately affected by multiplicative noise (Speckle noise) which impacts quality performance of SAR images. The Eq. (2) represents basic representation model of speckle noise in SAR images. The logarithmic transformation of speckle noise is in turn converted into additive noise which is represented as

$$\log\left[D\left(i,j\right)\right)\right] = \log\left[I\left(i,j\right)\right)\right] + \log\left[M\left(i,j\right)\right)\right] \quad (3)$$

After the transformation the above equation can be rewritten as

$$F(i,j) = X(i,j)*Y(i,j) \quad (4)$$

Where log[D(i,j)] is denoted as F(i,j) and followed by log[I(i,j)] and log[M(i,j)] are rewritten X(i,j) and Y(i,j) as respectively.

Despeckling of SAR imagery using directional smoothing and hard thresholding

The denoising and enhancement process of a Synthetic Aperture Radar (SAR) images are major challenging task in image analysis. It involves two processes as pre-processing and post processing of SAR image.

In preprocessing, directional smoothing and hard thresholding methods has to be followed to remove the speckle noise from radar image whereas image enhancement is performed in post processing for that hybrid Laplacian Gaussian filtering (HLGF) has been utilized. For efficient image despeckling and enhancement is carried out efficiently by using Dehazing algorithm in a step by step manner.

The most important task of reduction of speckle noise in Synthetic Aperture Radar (SAR) images is preprocessing action. The source origin of speckle noise is owing to random interference in a coherent nature that is mainly coming from number of scattering component appeared on earth surface along with the length of Synthetic Aperture Radar (SAR). For suppression of speckle noise there are numerable methods are developed. In SAR images popularly used techniques are Kuan, Wiener, Median, Weighted median, Frost, and Gaussian filter etc.

Selecting an optimum threshold value is important task in image despeckling process. Because, a small threshold value will leads to retaining images with noisy coefficients whereas large threshold value leads to loss of coefficients which carries image feature information. For denoising process, there are two thresholding techniques were used namely soft thresholding and hard thresholding. In Hard thresholding, image pixel coefficients are preserved whereas in soft thresholding method the pixel coefficients are shrinked above the absolute threshold value. The main disadvantage of soft thresholding is image having poor resolution when applied in SAR applications. Hence, hard thresholding method has been utilized in proposed work. Here, to preserve tiny features of SAR image during preprocessing directional smoothing and hard thresholding are performed.

Directional smoothing

When performing despeckling process the image edges are becomes blurred which degrades image quality. To mitigate this problem, conditioning algorithm called edge directional smoothing algorithm is utilized to protect the images. Step by step procedure of edge smoothing using directional smoothing technique. For convenience, we select three masks of size 3 × 3, 5 × 5 and 7 × 7.

Algorithm for Directional Smoothing

Step1: Start

Step2: Read the image pixels.

Step3: Compute the average of individual image pixels and sum them in each direction.
Then, calculated values are stored in an array denoted as V.

Step4: Replace the center pixel value by Index, I (V1)
The index value is the minimum value of absolute value of V.

Step5: Repeat the above procedure for whole image

Step6: Stop

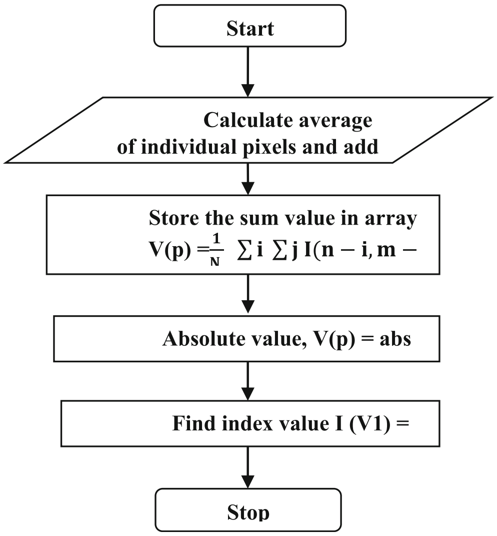

Fig. 2 Flowchart of Directional Smoothing Algorithm

Now the total average pixel values is computed and stored in array denoted as V which given in Eq. (5).

$$\mathrm{V(p)} = \frac{1}{N}\sum_i\sum_j \mathrm{I}(n-i, m-j) \quad (5)$$

And absolute value of V1 (p) is defined as

$$\mathrm{VI(p)} = \mathrm{abs}(v(p)-x(r,c)) \quad (6)$$

Where x(r,c) represents value of center pixel and minimum value of absolute of V1 is called as V (Index) is given by

$$\mathrm{Index}, \mathrm{I(VI)} = \mathrm{Min(VI)} \quad (7)$$

The flowchart of Directional smoothing algorithm is shown in Fig. 2.

Hard thresholding

Hard thresholding methods provide an optimal threshold to eliminate speckle noise in SAR images. This process can be accomplished by utilizing a feedback loop to optimize threshold value. Before applying hard thresholding technique, gray level based log transformation must be performed which helpful in image enhancement process. The log transformation of the image is stated in Eq. (5) as

$$\mathrm{Z} = \mathrm{k}^*\log(1 + r) \quad (8)$$

Here, k is denoted as a constant and it is assumed with initially r≥ 0. The term 'r' is represents a pixel value of input SAR image whereas 'z' is the pixel value respect to the output image which is got after log transformation. Additionally, the value '1' is added since the input pixel value is zero then log becomes infinity. In order to handle this situation and also maintain minimum value at

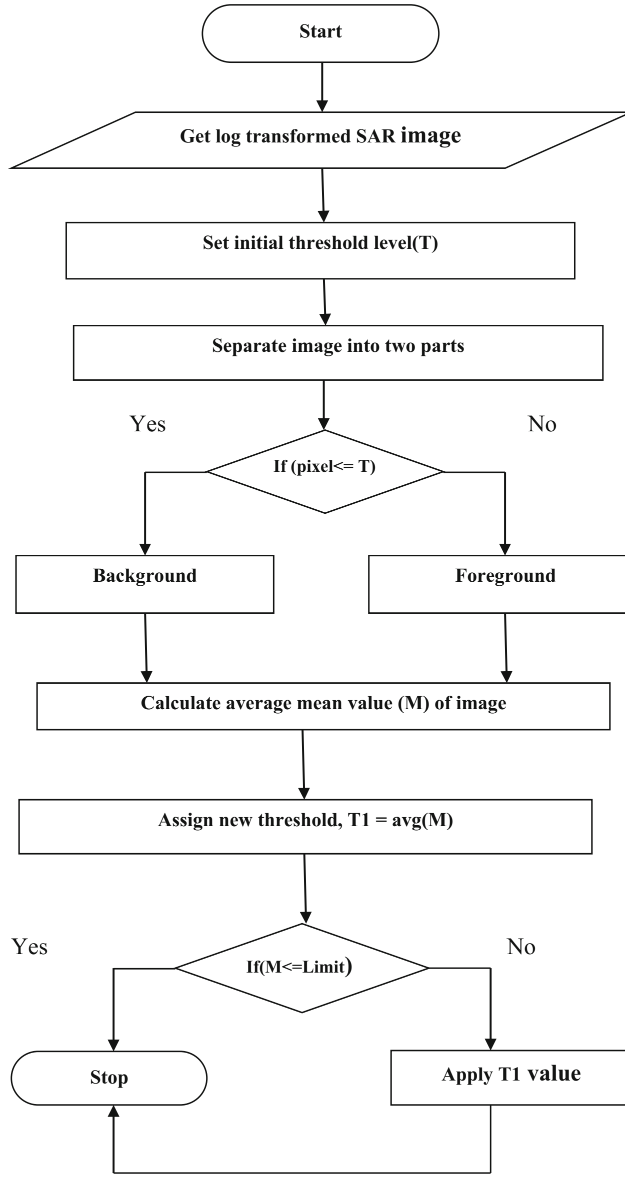

Fig. 3 Flowchart of Hard Thresholding Transformation

least '1'. According to decision of researchers the value of k is adjusted which is based on need of image enhancement. Consider the two variables namely p and q which represents observed image and speckled SAR image respectively. And S denotes speckle noise is given in the Eq. (9)

$$\mathrm{p} = \mathrm{q}^*\mathrm{S} \quad (9)$$

The statistical analysis of speckle noise involves complex in systematical analysis and conceptual modeling. The above Eq. (2) denotes transformation from multiplicative noise into additive noise and next Eq. (3) represents log transform on speckled image which eliminates signal dependency of the speckle noise. After applying the threshold value and then inverse log transformation is performed. For each pixels threshold value is setting before converting grayscale image to binary. For assigning

Algorithm for setting optimum threshold value

Step1: Start

Step2: Choose initial threshold level (T) (Typically eight bit value of the original image).

Step3: Separate the original image into two parts based on following conditions.

Step3.1:Pixel values less than or equal to threshold level. Set it as Background

Step3.2:Pixel values are greater than the threshold level. Set it as Foreground.

Step4: Calculate average mean values (M) of both background and foreground image.

Step5: Assigning the new threshold (T1) by averaging two mean values.

Step6: If difference between previous threshold value and new threshold value is below the limit Stop the procedure. Else goto Step7.

Step7: Else apply the new threshold level to original image.

Step8:Stop

threshold value image is considered into two parts as background and foreground.

The selected threshold value is based on the below Eq. (10)

$$\mathrm{T}_{\mathrm{Value}} = \sigma n^2 \sqrt{2\ logN} \tag{10}$$

Where σ is Noise standard deviation and N is total image size. The image pixel coefficients are demonstrated as variable in random nature. Therefore, the Eq. (10) can be rewritten as follows

$$\mathrm{T}_{\mathrm{opt}} = \min\left(\mathrm{T}_{\mathrm{Value}}, \sigma n^2\ \sqrt{s\ logN}\right) \tag{11}$$

After the completion of transformation process, Dehazing algorithm to be followed for image enhancement which further helpful for analyzing proposed performance metrics.

The flowchart of Hard Thresholding Transformation as shown in Fig. 3. After the completion of transformation process, Dehazing algorithm to be followed for image enhancement which further helpful for analyzing proposed performance metrics efficiently.

Image enhancement using hybrid laplacian gaussian filter (HLGF) using dehazing method

After completion of despeckling process which is done by directional smoothing and hard thresholding methods Dehazing algorithm has been performed. The image can be enhanced by Dehazing method using Hybrid Laplacian Gaussian Filter (HLGF). The mathematical form of HLGF is given in Eq. (12).

$$\frac{\partial u}{\partial t}(i,j) = \nabla.(\mathrm{E}\nabla\mathrm{S}(\mathrm{i},\mathrm{j})) \tag{12}$$

With some initial conditions S_0 (i) = S (i,j = 0) and S (i,j) is an noisy image whereas E is control function which handles entire process, based on image structure.

$$S_j = \nabla.(c(s)\nabla \mathrm{M}) \tag{13}$$

Where, c(s) representing Neumann boundary constant. and considered noisy image as the initial condition.

And

$$c(s) = \frac{1}{1+\frac{s2-s02}{s0(1+s02)}} \tag{14}$$

Where s (i, j) is a constant variable that holds instant variation of image pixel values.

And consider approximated value of c(s) as

$$c(s) = \frac{1+\frac{1}{s2}}{1+\frac{1}{s02}} \tag{15}$$

In order to efficiently improve image enhancement, we introduced additional mechanisms to improve the proposed system performance and modified equation is

$$S_j = -\nabla\left(c\left(|\nabla S|2S_{\eta\eta} + c(|\nabla S|2S_{\varepsilon\varepsilon})\right)\right) \tag{16}$$

Here the symbol Δ denotes Laplacian Gaussian operator (LGO) and

$$\mathrm{c}(|\nabla S|) = \frac{1}{1+\frac{(|\nabla S02|)}{k2}} \tag{17}$$

And

$$S_{\varepsilon\varepsilon} = \frac{S_{ii}S_{i2} + 2S_iS_j + S_{jj}S_{j2}}{S_{i2} + S_{j2}} \tag{18}$$

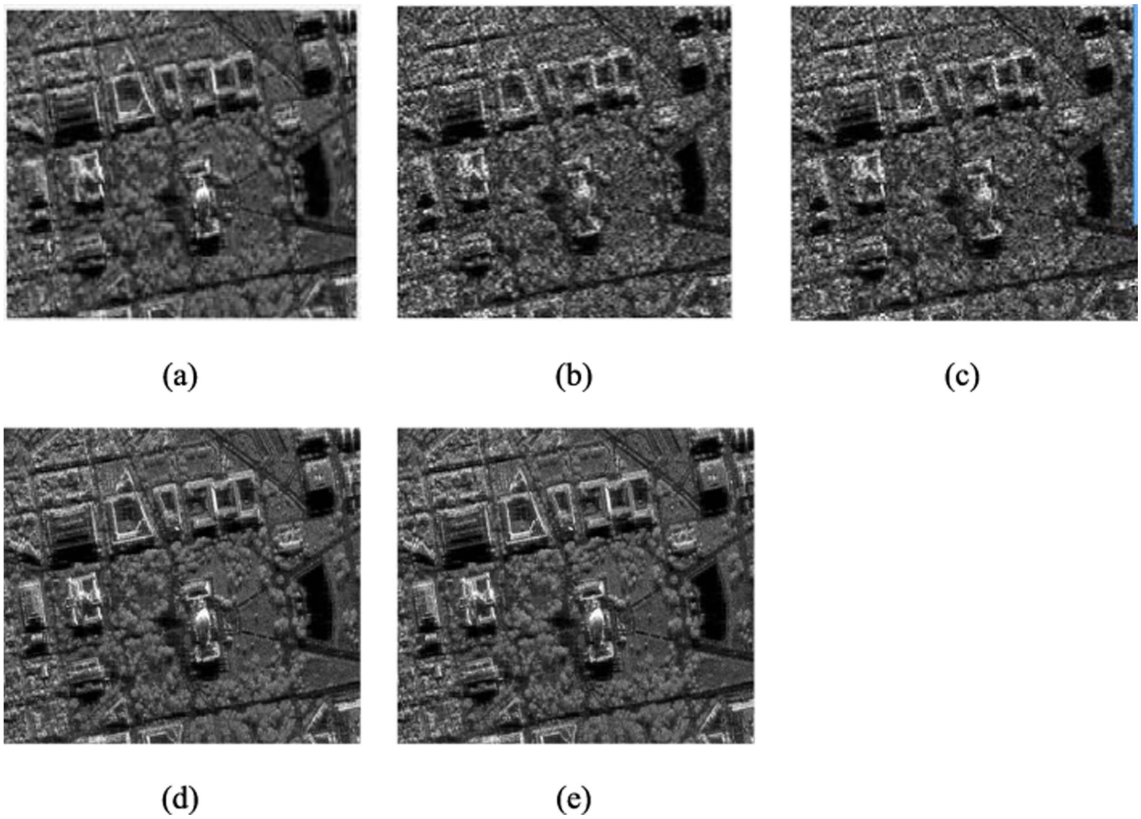

Fig. 4 Step by Step process of proposed approach. **a** Original SAR image, **b** Speckled SAR image, **c** Despeckled image after applying Smooth filtering and hard thresholding and **d** Enhanced image by applying HLGF based Dehazing method **e** Despeckled SAR image

Since η and ε are the derivative variables of direction in order to smoothening the images. It is represented as $\eta = \frac{[-Mi]}{\sqrt{Mi2+Mj2}}$ and $\varepsilon = \frac{[-Mj]}{\sqrt{Mi2+Mj2}}$.

Where, n and ξ are directional derivative parameters that are represented as unn and $u\xi\xi$.

The Laplacian Gaussian Operator (LGO) calculates spatial features, which means that in areas where the image has a constant value of intensity, results in intensity gradient becomes zero. Also LGO response will be zero. The LGO response is positive on darker side and negative on lighter side. The LGO responses from different view of image edges are discussed below. The obtained enhanced image is shown in the Fig. 4d respectively.

- At a long distance from the edge. LGO = zero.
- View of one side of the edge. LGO = Positive.
- View of other side of the edge. LGO = Negative.
- Some points in between, on the edge itself. LGO = Zero.

Experimental results and discussion

The performance evaluation of proposed algorithm is obtained by statistical methods like Mean Square Error(MSE), Peak Signal to Noise Ratio (PSNR), Speckle Suppression Index (SSI) and Speckle Suppression and Mean Preservation Index (SMPI).PSNR,SSI and SMPI should be high for better filtering algorithm.

Mean square error(MSE)

It indicates the average square difference of pixels between the original image g(x,y) and speckled image f(x,y).MSE value should be low and is defined as

Table 1 Comparison of existing method [21] with proposed [HLGF] before log transformation process

Sl.No	Speckle Noise Variance	Z = k*log(1 + r)	PSNR for Speckled Image Before Log Transformation	
			DWT [21]	Proposed Method [HLGF]
1	0.04	k = 0.1	22.1004	22.1256
2	0.1	k = 0.1	18.1837	18.1936
3	0.2	k = 0.1	15.2809	15.2869
4	0.3	k = 0.1	13.6368	13.6458
5	0.4	k = 0.1	12.5402	12.5254
6	0.5	k = 0.1	11.8244	11.8354
7	0.6	k = 0.1	11.3262	11.3252

Table 2 Comparison of existing method [21] with proposed [HLGF] after log transformation process

Sl.No	Speckle Noise Variance	Z = k*log(1 + r)	PSNR for Speckled Image After Log Transformation	
			DWT [21]	Proposed Method [HLGF]
1	0.04	k = 0.1	13.0516	22.1256
2	0.1	k = 0.1	12.3350	18.1936
3	0.2	k = 0.1	12.8605	15.2869
4	0.3	k = 0.1	12.6293	13.6458
5	0.4	k = 0.1	12.3228	12.5254
6	0.5	k = 0.1	12.1147	11.8354
7	0.6	k = 0.1	11.9675	11.3252

$$\mathrm{MSE} = \frac{1}{\mathrm{MN}} \sum\sum[\mathrm{g}(\mathrm{x},\mathrm{y}) - \mathrm{f}(\mathrm{x},\mathrm{y})]2 \quad (19)$$

Peak signal to noise ratio (PSNR)

PSNR gives quantitative evaluation. It is calculated between original image i and noisy image. Higher PSNR value indicates higher quality.

$$\mathrm{PSNR} = 20\log_{10}\left[\frac{\mathrm{Max_i}}{\sqrt{\mathrm{MSE}}}\right] \quad (20)$$

Table 3 Comparison of existing method [16] with proposed [HLGF] in terms of SSI and SMPI parameters

SI.No	Methods	Moderate factor β	Reference paper [16] SSI	Proposed Method [HLGF] SSI
1	AFTV	0.6672	0.9583	0.9783
2	TV	0.4390	0.9462	0.9662
3	ATV	0.9433	0.9766	0.9966
4	TMED	0.0666	1.0001	1.0201
5	ATMED	0.4438	0.9865	0.9965
6	TMAV	0.1681	0.9999	1.0499
7	HTMED	0.0074	0.9974	1.0974
8	HATMED	0.4467	0.9834	0.9935
9	HTMAV	0.2127	0.9978	1.0698
10	GWF	0.3634	0.9804	0.9989
11	GEF1	0.1349	0.9675	0.9879
12	GFW2	0.4145	0.9682	0.9987

Table 4 Comparison of proposed method with other techniques

Technique	PSNR	MSE
Proposed algorithm	67.8964	0.015457
Weiner Filter	61.2079	0.198
Lee Filter	60.7207	1.0975
Mean Filter	60.8248	1.073
Homomorphic Lee Filter	60.4542	1.168
Frost Filter	59.8922	1.330
Homomorphic Frost Filter	61.7952	1.3714
Kuan Filter	60.7317	1.096
Homomorphic Kuan Filter	59.4639	1.166
Hard Threshold	60.0867	1.097
Soft Threshold	60.0245	1.079
Bayesian Threshold	59.0558	1.2808
Normal Threshold	59.0267	1.2895

Speckle suppression index (SSI)

SSI is the coefficient of variance of filtered image normalized by that of the original image, which is defined as

$$\mathrm{SSI} = \frac{\sqrt{\mathrm{Var}(\mathrm{X})}}{\mathrm{Mean}(\mathrm{X})}\,\frac{\mathrm{Mean}(\mathrm{Y})}{\sqrt{\mathrm{Var}(\mathrm{Y})}} \quad (21)$$

Where X is the filtered image value and Y is the original image value. Smaller SSI value denots greater the speckle suppression.

From the above Fig. 4a represents original SAR image and after added noise to the input SAR image called speckled image is shown in Fig. 4b. Then, speckled image can be Despeckled by applying directional smoothing and hard thresholding and selects an optimal threshold value that is used to suppress the speckle noise in SAR images. The Despeckled image is shown in Fig. 4c. Followed by

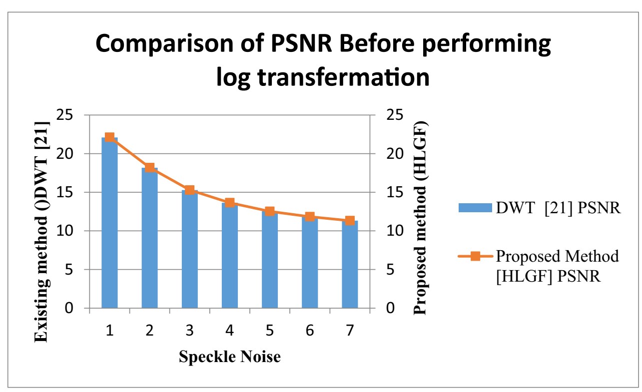

Fig. 5 Comparison Chart between PSNR of Existing method [21] with proposed method (before log transformation)

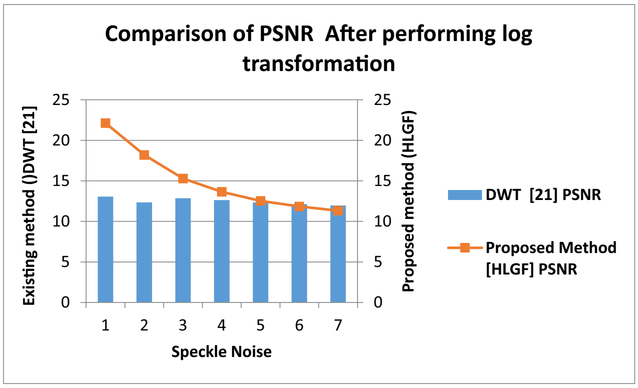

Fig. 6 Comparison Chart of PSNR of Existing method [21] with proposed method (after log transformation)

despeckling process, image is enhanced by HLGF based Dehazing method and enhanced image is shown in Fig. 4d. The Fig. 4e represents Despeckled image which is better than original SAR image. Tables 1, 2, 3 and 4 are observed the various comparison between proposed method with existing methods. Table 1 represents comparison of existing method [21] with proposed [HLGF] before log transformation process. Table 2 represents Comparison of existing method [21] with proposed [HLGF] after log transformation process. Table 3 represents comparison of existing method [16] with proposed [HLGF] in terms of SSI and SMPI parameters. Table 4 observed that Comparison of Proposed method with other techniques.

The performance of proposed system is compared with existing approaches which depicts in the following graph via its numerical value of parameters such as PSNR, SSI.

From the Fig. 5 observed that l PSNR before performing log transformation is measured with the conventional method Discrete Wavelet Transform [21], where is proposed PSNR is better than existing method.

From the Fig. 6 observed that l PSNR after performing log transformation is measured with the conventional method Discrete Wavelet Transform [21], where is proposed PSNR is better than existing method as shown in Fig. 7.

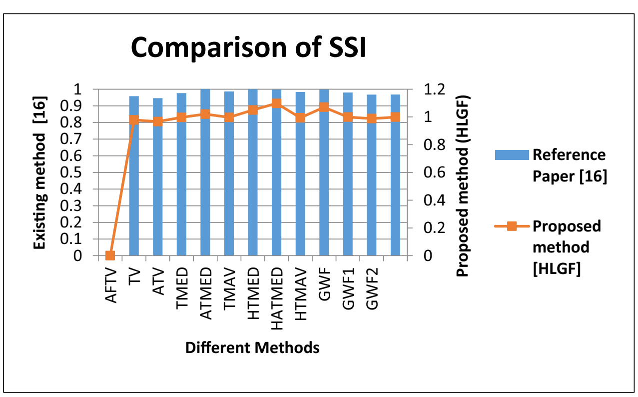

Fig. 7 Comparison Chart between SSI of Existing method [16] with proposed method

Conclusion

Results shows that the proposed method for despeckling is better than existing statistical and homormorphic based statistical filters. In First stage is despeckling process which is based on directional smoothing and hard thresholding technique and second stage is image enhancement process which is based on applying HLGF filter. The proposed method enforces Smooth filtering and Hard thresholding for speckle suppression and also applied HLGF based dehazing method for image enhancement. The proposed approach is implemented in MATLAB environment and implemented system parameters such as SNR, PSNR and SSI are obtained which are compared with existing methods.

Acknowledgements The Author would like to thank MSTAR database to access SAR images.

Compliance with ethical standards

Conflict of interest No conflicts of interest: Author 1 & 2 declares that they have no conflict of interest.

Human and animals rights All procedures followed were in accordance with the ethical standards of the responsible committee on human experimentation (institutional and national) and with the Helsinki Declaration of 1975, as revised in 2008″.

Informed consent Informed consent was obtained from all patients for being included in the study.

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