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DESPECKLING OF SYNTHETIC APERTURE RADAR SATELLITE IMAGERY USING VARIOUS FILTERING TECHNIQUES

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ABSTRACT

Active microwave imaging systems such as Synthetic Aperture Radar (SAR) is the Earth observation satellite which works day/night, irrespective of the unconditional weather condition. Satellite Synthetic SAR images are predominantly affected by multiplicative speckle noise. Noise is an unwanted signal, which suppresses the quality of the image and makes the processing of the image difficult and should be removed or reduced with the help of filtering techniques. Different filtering techniques like Min, Max, Mean, Median, Statistical and Adaptive filters are applied on the speckle affected SAR images captured by RADARSAT-1 and Sentinel-1A satellites. The results are compared qualitatively and from the obtained results, it is observed that the Median filter is able to suppress speckle noise by preserving the required details and is giving the promising results compared to the other filters.

Keywords: filter noise, sentinel-1A, speckle, synthetic aperture radar (SAR).

INTRODUCTION

Remote sensing is an acquisition of reliable information about a phenomenon or environment by the remote sensors without being physically in contact with it [1]. Images obtained using remote sensing are used in different applications like land cover mapping, oceanography, updating of geographical databases, urban studies, natural disasters, [2] etc., Images are sensed remotely with the help of ground borne or airborne or space borne sensors by detecting the electromagnetic energy scattered from or emitted from or reflected by the earth's surface [1]. The ground borne and airborne sensors has limited spatial resolution. Airborne sensors are very costly. Space borne sensors are cost-effective and covers large geographical areas with periodical re-visit of the same area [1].

The satellite sensors can capture images in the visible, infrared, thermal and microwave bands of the electromagnetic spectrum. Passive remote sensor and active remote sensor are the two different types of satellite sensors [1]. Optical remote sensor is an example of passive remote sensing which depends on the sunlight. Optical remote sensors can operate in visible, infrared and thermal bands of electromagnetic spectrum. The Synthetic Aperture Radar (SAR) is a remote sensing device which provides its own artificial radiant energy source for illumination. SAR operates in the microwave portion of the electromagnetic spectrum.

The signal and the noise are statistically independent of each other. Random variation of intensity of the pixel is called noise and it is unwanted. Noise is categorized [3] into Gaussian noise, uniform noise, impulse noise [4-5] (salt and pepper noise), Rayleigh noise, Erlang (gamma) noise, exponential noise, speckle noise [6, 7], etc., Reduction of noise is very crucial step in the image processing, where noise signal is present in the image. This unwanted noise should be removed from the images, as noise can be often interpreted as target by mistake. Image de-noising helps to improve the quality of the image and makes the analysis of the image effective.

SAR is the side-looking imaging Radar which can only measure the backscattered signal returned towards the antenna [1]. SAR images are satellite images [3]. SAR Image contains information about two things, structure and dielectric properties of the land surface [1]. The strength of the signal reflected is the backscattered coefficient (sigma naught) and is expressed in decibels (dB). SAR images are popular and most often used [6] by the researchers due to SAR's capability of obtaining images of large areas with high resolution during day and night and in all weather conditions [3], with minimal atmospheric effects. Different SAR missions are JERS-1, ALOS-1/2, Envisat, Sentinel-1, Radarsat-1/2, Terra SAR-X, COSMO-Skymed, [9, 10] etc., SAR image is affected with multiplicative noise due to backscattering [11]. The multiplicative noise present in SAR degrades the quality of the valuable/required information in the image. The speckle noise should be removed/ it should be suppressed. In literature various types of filters are proposed to remove/suppress the unwanted noise present in the SAR image. In this paper we discuss about various filters to suppress the speckle noise from the SAR images.

In this study, RADARSAT-1 and Sentinel-1A data are considered. RADARSAT-1, equipped with an advanced radar sensor SAR, is the Canada's first earth observation satellite [11]. This was launched in November 1995 and it was active till March 2013.RADARSAT-1 is a single polarization (HH) earth observation satellite with 24 days repeat cycle. HH stand for Horizontal transmit and Horizontal receive. RADARSAT-1 is a right-looking C-band satellite operating with microwave frequency of 5.3GHz, with swath width of 45km and 8m spatial resolution [13].

The Sentinel-1A SAR image is acquired on 1st March 2017 covering the Gorakhpur area located in the North-Eastern part of Uttar Pradesh (UP) state in India .Sentinel-1A is a dual polarization (VV+VH) radar, near-polar sun synchronous orbit satellite with 12 day repeat cycle [15]. VV stand for Vertical transmit and Vertical receive, VH stand for Vertical transmit and Horizontal receive. Sentinel-1A is a C-band SAR sensor operating with microwave frequency of 4GHz [15] and its data products are distributed by ESA (European Space Agency). The image was acquired when satellite was ascending (South to North). The latitude and the longitude of the study area are 26.83’24” to 26.69’96” North and 83.49’11” to 83.49’22” East respectively.

This paper is organized as follows: Section 2 discusses about speckle noise; section 3 describes the methodology applied for removing speckle noise removal using filters with a neat flowchart and filtering techniques. Section 4 gives the Results and discussions with supporting diagrams and detailed explanation. Section 4 gives the conclusion about the paper.

Speckle noise

Speckle noise in medical and SAR data degrades the image quality and hence should be removed for obtaining better results [16]. It is primarily caused due to coherent backscattered signals from multiple targets [3, 9, 13]. Speckle noise is represented using the mathematical Eq. (1). Removal of multiplicative noise from the image is difficult compared to the additive noise [17].

$$p_{i,j} = o_{i,j}.n_{i,j} \tag{1}$$

Where,

$p_{i,j}$ represents the degraded intensity for each pixel;
$o_{i,j}$ represents the original image;
$n_{i,j}$ represents the multiplicative noise

SAR images have a wide range of military and scientific applications. SAR images affected with speckle noise lessen the image quality and reduce the effectiveness of the processing algorithm [16]. Before processing the image, speckle noise must be removed in pre-processing step [16]. Several methods are used in literature to eliminate speckle noise based on different mathematical models of the phenomenon. One method is to employ multiple look processing also known as multi-look processing. The second method involves using adaptive and non-adaptive filters. Non-adaptive filtering is simple to implement and requires less computational power. Adaptive speckle filtering is better at preserving edges and detail in high texture areas such as forests or urban areas. Lee, Frost, etc are some of the adaptive filters [16].

Dataset used

In this study, RADARSAT-1 and Sentinel-1A data are considered. RADARSAT-1, equipped with an advanced radar sensor SAR, is the Canada’s first earth observation satellite (Natural, 2014). This was launched in November 1995 and it was active till March 2013.RADARSAT-1 is a single polarization (HH) earth observation satellite with 24 days repeat cycle (Satellite, 2019). HH stand for Horizontal transmit and Horizontal receive. RADARSAT-1 is a right-looking C-band satellite operating with microwave frequency of 5.3GHz, with swath width of 45km and 8m spatial resolution (Satellite, 2019). The Sentinel-1A SAR image is acquired on 1st March 2017 covering the Gorakhpur area located in the North-Eastern part of Uttar Pradesh (UP) state in India .Sentinel-1A is a dual polarization (VV+VH) radar, near-polar sun synchronous orbit satellite with 12 day repeat cycle(Copernicus, 2018). VV stand for Vertical transmit and Vertical receive, VH stand for Vertical transmit and Horizontal receive.Sentinel-1A is a C-band SAR sensor operating with microwave frequency of 4GHz (Copernicus, 2018) and its data products are distributed by ESA (European Space Agency). The latitude and the longitude of the study area are 26.83’24” to 26.69’96” North and 83.49’11” to 83.49’22” East respectively.

METHODOLOGY APPLIED

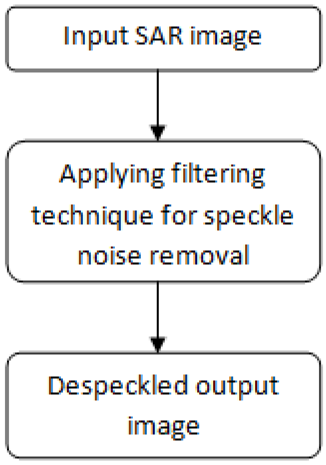

Figure-1. Procedure applied for de-noising the SAR image.

Filtering of speckle noise is an essential procedure in most classification and target detection systems [16]. Several speckle reduction techniques have been developed from the past two decades for removing speckle noise by preserving edges. Different filters for removal of speckle noise are Geometric filter, Linear filter, Weiner filter, Min filter, Max filter [16], Adaptive filter [19], Mean filter [20], Median filter [21-22], Gaussian filter, Statistical filter etc., The procedure for removal of noise in SAR images is shown in the Figure-1. The SAR image which is affected by speckle noise will be used as input to the filter and by applying the filtering technique on the image, the despeckled output image will be obtained.

VARIOUS FILTERING ALGORITHMS

Speckle filter makes use of a square window (or) kernel (or) mask (3x3/ 5x5/ 7x7, etc.,) [24] which moves over each pixel in the image until it covers the whole image. The central pixel of the moving window will be substituted by applying a mathematical calculation. A brief definition and mathematical formula for various speckle reduction filters are given below:

A. Min filter

The Min or Minimum filter replaces the central pixel intensity value in the running kernel with the smallest value of its neighbourhood [18] and can be used for finding the darker pixel. It enhances the brighter pixels in the image and works better for removing the salt noise. It is performed by using the mathematical Eq. (2) as given below:

$$p(k,l) = \min_{(i,j)\in N_{kl}} \{g(i,j)\} \quad (2)$$

Where,
p(k,l) represents the new image
g(i,j) represents the old image kernel pixel intensities.

B. Max filter

The Max or Maximum filter replaces the centre pixel value in the running window with the largest value of its neighbourhood [14] and can be used for finding brighter pixel in the image. It enhances darker pixels in the image and works better for removing the pepper noise. It is performed by using the mathematical Eq. (3) given below:

$$p(k,l) = \max_{(i,j)\in N_{kl}} \{g(i,j)\} \quad (3)$$

Where,
p(k,l) $p(k,l)$ represents the new image and
g(i,j) represents the old image kernel pixel intensities.

C. Adaptive filter

When the image is processed, an Adaptive filter alters its basic behaviour and it can be designed for any domain [19]. It applies a spatially varying contrast stretch on the image. On some parts of the image, it acts like a Mean filter and on other parts of the image; it acts like a Median filter. Many types of Adaptive filters are designed with a similar theme and can be tuned for specific applications. Weiner, Kalman, etc are few Adaptive filters.

D. Statistical filter

This filter is based on the statistical approach. Suppresses only very high frequency variations in the imagery.

E. Mean filter

The mean or average filter is the maximum likelihood estimator for speckle reduction in stationary images [16]. It will not remove the speckle noise from the images but reduces to some extent. It is implemented by performing the local average operations using the mathematical Eq. (4) for kernel$M \times N$ MxN. For example, if 3x3$\times$ 3 neighbourhoods are considered, then neighbourhood matrix of any pixel will have 9 pixels. It works as a low pass filter and blurs the image [14], and it is not efficient technique for removing speckle noise, as it blurs the resultant image [3].

$$p(k,l) = \frac{1}{MN} \sum_{i\in M} \sum_{j\in N} g(s,t)) \quad (4)$$

Where,
p(k,l) represents the new image pixels;
g(s,t) represents the old image;
MN represents the window range

F. Median filter

Median filter works similar to mean filter [3], but it is better than mean filter as it preserves the suitable details in the image. This filter considers each pixel in the image and looks at its nearby neighbours to decide whether or not it is represented of its surroundings. Instead of replacing the pixel value with the mean, like in mean filter, it replaces with median of the neighbourhood values. The median value is calculated by sorting all the pixel values from the surroundings into numerical order and then replacing the pixel being considered with the middle of pixel value. It is very popular image transformation filter, which filters the noise and also preserves the sharp edges [23].

RESULTS AND DISCUSSIONS

The image captured by RADARSAT-1(Courtesy: Google earth) is fine resolution image with HH polarisation and is shown in Figure-2(a) and it is input image [13]. From the input image, it can be observed that, it is more affected with speckle noise. Figure-2(b), 2(c), 2(d), 2(e), 2(f) and 2(g) shows the results obtained after applying the Min, Max, Statistical, Adaptive, Mean, Median filters respectively. These filters are evaluated with the kernel size of 3X3 using Erdas imagine tool.

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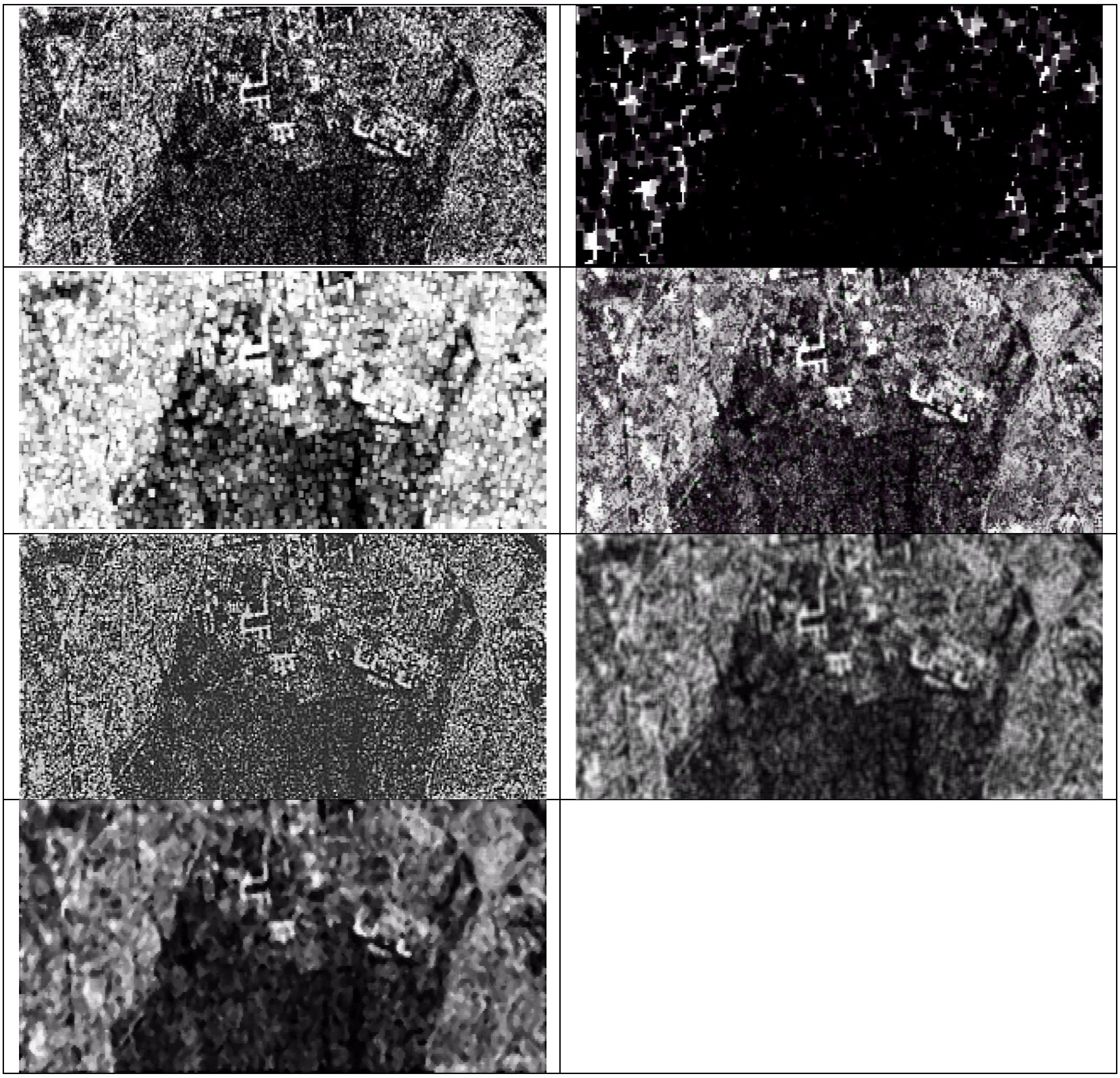

Figure-2. Comparison of the original image and the resultant images in (a) Input image (Credits: Google); (b) Min filter result; (c) Max filter result; (d) Statistical filter; (e) Adaptive filter result; (f) Mean filter result; and (g) Median filter result.

The image captured by Sentinel-1A (Credits: ESA) which is a Ground Range Detected level-1 processed image [15], considered as input image and shown in Figure-3(a) which is also affected with speckle noise. Figure-3(b), 3(c), 3(d), 3(e) and 3(f) shows the results obtained from Min, Max, Statistical, Adaptive, Mean, Median filters respectively. These filters are evaluated with the kernel size of 3X3 using Erdas imagine tool.

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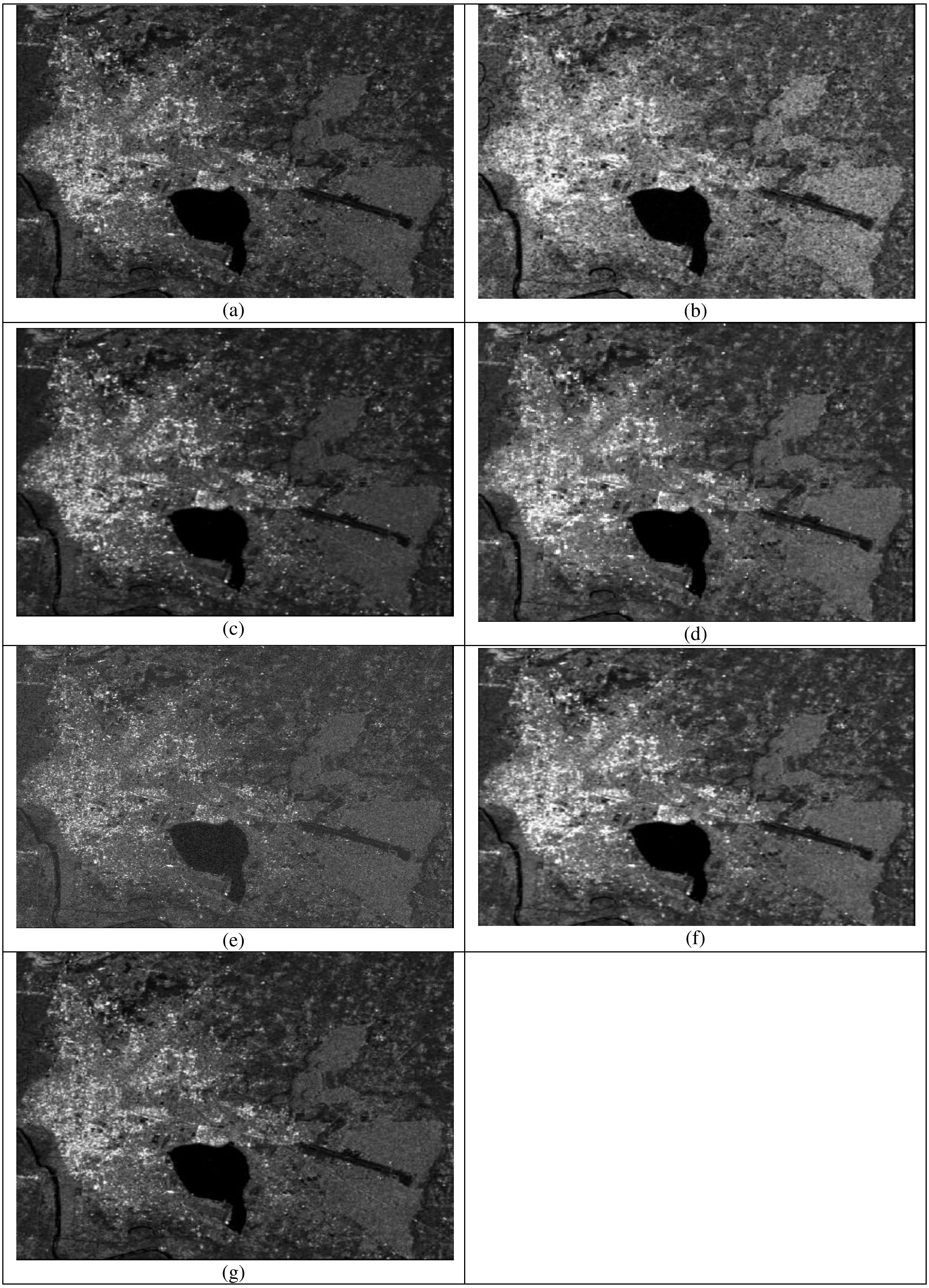

Figure-3. Comparison of the original image and the filtered images in (a) Input image (Credits: European Space Agency (ESA)); (b) Min filter result; (c) Max filter result; (d) Statistical filter; (e) Adaptive filter result; (f) Mean filter result; (g) Median filter result.

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Figure-2(a) is the image acquired by RADARSAT-1 and Figure-3(a) is the image captured by Sentinel-1A and is considered as input images, for the study. The SAR images which are obtained by coherent radiation are affected with speckle noise [8] (refer Figure-2(a)). Presence of this kind of noise will decreases the quality of image and makes the interpretation difficult, both manual and automatic. In order to avoid such difficulties, before processing the image, the speckle noise should be removed by applying appropriate filtering techniques.

Different filtering techniques such as Min, Max, Adaptive, Mean and Median filters are applied on both RADARSAT-1 and Sentinel-1A images which are affected by the speckle. Figure-2(b) &3 (b) are the results of applying the Min filter on the RADARSAT-1 and Sentinel-1A images respectively. Min filter along with removal of noise, it substitutes the middle pixel value in the moving kernel with minimum pixel intensity value, resulting in the dark image (refer Figure-2(b) & 3(b)). Figure-2(c) & 3(c) are the resultant images obtained from applying the Max filter on the same. Max filter along with removal of noise, it substitutes the middle pixel value in the moving kernel with maximum pixel intensity value, resulting in the brighter image (refer Figure-2(c) & 3(c)). Min filter makes the images darker and the Max filter makes the image brighter. Min filter gives better results when the image is affected with salt noise and Max filter works better when the image is affected with pepper noise. Figure-2(d) & 3(d) are the results obtained from the Statistical filter. It takes more computation time and the resultant image obtained is brighter. Figure-2(e) & 3(e) are the results obtained by applying Adaptive filter on the input images. This filter removes the speckle but at the same time it blurs the image, losing texture and edge details. As shown in Figure-2(f) & 3(f) respectively, the image details are lost as when mean filter is applied, as it smoothens the image .The median filter (refer Figure-2(g) & 3(f)) gives better results compared to above filters [25], by reducing [8] speckle noise [26] and with minimal loss of edge and texture information.

CONCLUSIONS

Synthetic Aperture Radar (SAR) is an imaging system which is robust to weather conditions and atmospheric effects. Because of this, SAR has a wide range of military and scientific applications. Presence of speckle noise in the SAR image makes it difficult in clustering, edge detection, segmentation, etc., using processing algorithms. In this paper, removal of speckle noise in SAR imagery is done using various filtering techniques like Min filter, Max, Mean, Median, Statistical and Adaptive filters. By comparing the despeckled output image obtained from these filters, it can be established that the median filter is more effective in de-noising the image.

CONFLICT OF INTEREST

There is no conflict of interest.

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