A Study of SAR Despeckling Methods

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Abstract

To capture geographic images, optical sensors were used in past to analyze and extract information for numerous purposes ranging from mineral resources to survelance. But the limited availability of optical sensors use led to radar based sensors for continuous data capturing. In which, neither time constraint was involved nor the hinderance by atmospheric factors. The image captured with the synthetic aperture radars undergo the phenomena of speckle which is a granular noise triggered by the constructive or destructive supersition of received signals. The result of this interenfence affects the image quality and the retrivel of the information. To cope with this issue, numerous strategies were defined from local filters to non-local filters, transforms and combined solution through transforms and non-local filters as hybrid techniques. The studies of local, non-local and transforms were efficient but each having their limitation posed the question for improvent in denoising the images. The experiments conducted showed that hybrid solutions outperform their predecessors for which this study is conducted to analyze and evalute the techniques and explore the factors in hybrid techniques that can efficiently despeckle the synthetic aperture radar images by maintaing the image quality and details.

Keyword: Synthetic Aperture Radar (SAR), Optical Sensors, Radars, Speckle, Noise, Local Filters, Non-Local Filters, Wavelets, Transforms

1 Introduction

Optical sensors image capturing is a passive phenomenon that is dependent on the visible spectrum of sunlight which is captured by the sensors. The SAR imaging synthesizes the working of actual radar and is an active image capturing process in which signals are transmitted by the carrier and received by the same radar The distance carrier flies between transmission and receiving of signals is the reason its synthetic aperture radar else the hundreds of meter long radar have to be carried which would make the process ineffective and costly. The figure 1 explains the working of active and passive image acquisition processes. In the upper portion of the image, optical sensor captures the reflected sunrays from objects and transfers it to the ground station. The reason of it being obsolete is the visible spectrum constraint to be used only in the day time and shorter wavelength limits the application for only the objects above the ground surface.

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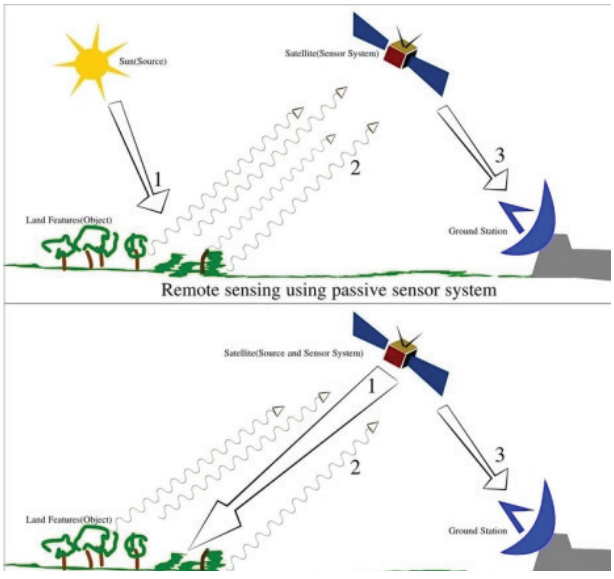

Figure 1: Remote sensing using optical and radar

Whereas the active sensing techniques self illuminates the area of interest in a side looking direction flew by the radar carrier and covering the distance to synthesize the diameter of radar to capture the reflected signals from the object [1-3].Active sensing supersedes the passive by three areas that are all day and night image acquisition because of microwave signal instead of visible spectrum which having higher wavelength strengthens the image acquisition process to capture high quality images and not restricted to the ground objects. The higher wavelength of microwave signals can penetrate the earth surface enabling it for exploring the underlying structure and resources. The microwave signals are also not hindered by the atmospheric factors like cloud, rain etc. The synthesizing of radar in active image capturing the images encounter speckle that degrades image quality and obstructs the extraction of information [7-8]. The table 1 presents a brief comparison among the two remote sensing techniques.

Table 1: Comparison of Optical and Radar based Image Acquisition

	Optical Sensors	Radar Based
1.	Passive Image	Active Imaging
2.	Use of Visible spectrum	Use of Microwaves
3.	Non penetrable	Can penetrate the Earth Surface
4.	Works only in Daylight	Can Work both in Day and Night
5.	Effected by atmosphere	Not Effected by atmosphere
6.	Not efficient results	Efficient results

2 Material And Methods

Radar airborne carrier satellite emits the microwave signals towards the earth surface in a side looking direction and travels the distance to capture the transmitted signal. The transmitted microwave when received by the radar encounter reflection and scattering of the signals. When

the incidence angle of the signal is same as reflection angle it is called reflection and scattering is when the signals deviate from their course due to the object. These two factors together cause disturbance in the received signals either constructive or destructive interposition known as speckle. The effect of speckle is difficulty in understanding the images for information extraction and features of images. To overcome the speckle issue in the radar images, various solutions have been applied that are filtering the images through local, non-local filter, transforms and combination of transforms with non- local [9-10]. In the early 1980s , Lee filter was proposed by Jong Sen Lee that served as the foundation in local filters for despeckling techniques where the regions were uniform and performed well ,but the regions with non-uniform structure lee filter smoothened the structures of region that altered the image. Lee compelled the filtering by utilizing mean and neighborhood change of pixels keeping up edge sharpness and refined points of interest. That favored its application in exploiting the image insights [11].Kuan filter was the next advancement in local filters that did not took any approximation while denoising the images and produced better results than the lee filter. In kuan filter a weighted function was used for which an additive noise model was generated for the existing multiplicative noise. [12]. Frost filter was proposed in local filters category with the objective to limit the mean square between the captured and denoised synthetic aperture radar image [13].To overcome the limitations of local filters non-local filters were introduced with the principle to take the information an image provides that is pixels similarity and prediction before filtering the captured image.To overcome the limitations of local filters, non-local filters were introduced with the principle to take the information an image provide that is pixels similarity and prediction before filtering the captured image. The non-local filters executed to perform better results than the local filters with the requirement of more powerful computation machines. With this principle, buades presented a non-local solution to denoise based on the non-local average algorithm. The non-local mean algorithm by buades is weighted mean function of neighboring pixels in place of average, after which weighted average of pixel similarity is calculated. To extend the work of buades, Charles alban et all presented an enhancement to the means with nonlocal as noise distribution model. In Charles model probabilistic patch filtering is done for which weighted maximum likelihood estimation of synthetic aperture radar image calculated and weights are extracted in a data-driven way. Probabilistic model runs iteratively solves the problem by computing the similarity among the calculated noised patches and patch from last iteration to enhance the weights of the function at each iteration. Iteratively solving and updating the weights results in better performance. The same process can be used for guassian and additive noised images. The iterative process on hand increases the performance but suppresses the thick and dark details in a regularized image. [14-15]

While the efforts being done to denoise, the images having guassian noise was successful but image details were not preserved. For which zhong proposed non-local Bayesian filter to denoised and preserve image details. The work done by zhong was based on Lee sigma filter an extension of earlier Lee local filter and Charles alban work of the patch probability phenomena [16].Bayesian addressed speckle elimination by the use of improved sigma filter [17] for preservation of image details with moving window having size from 5×5, 7×7, 9×9, 11×11 and above; along with scanning rectangular windows. The advantage of doing so provides filtering images with the azimuth pixel spacing higher than the range

pixel spacing. In general, higher speckle reduction is achieved using a larger window, but computational load will also be increased. This overcomes the bias in the estimates, unfiltered black pixels, and smearing of strong targets and addition of MMSE estimator for the adaptively filter the image[18].Another contribution to non-local filters is by Bin Xu which uses the nonlocal sparse model by iterative filtering mechanism for synthetic aperture radar images. The captured image is at first transformed to logarithmic image domain. The transformed images are then denoised by nonlocal sparse model and iteratively regularizing. At each turn of the iteration, noise factor is updated and variance is calculated. For a patch in noised region similar to those are found, grouped and passed through sparse coding. The filtered patches are combined to obtain the image without noise. Iterative regularization and non-sparse model, result into higher computational complexity of model in comparison to the techniques explained before [19].

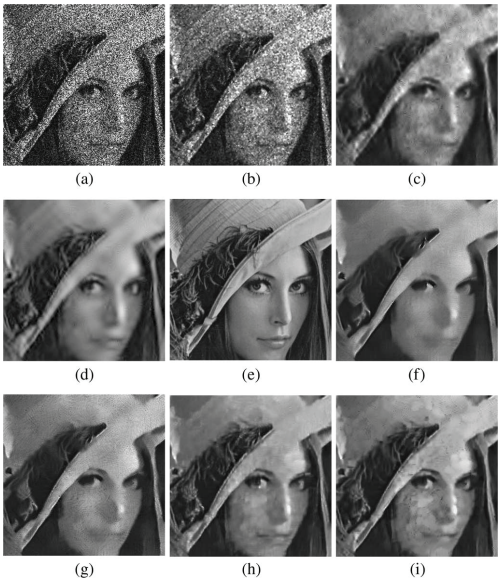

Figure 2: Zoom of filtered images for Lena corrupted by one-look speckle (a) Noisy image (b) Frost (c) SA-WBMMAE (d) MAP-S. (e) Original image (f) PPB (g) H-PPB (h) SAR-BM3-D (i) H-BM3-D

To de-speckle the polari metric and interferometry images, NL-SAR framework is proposed as an extension of Non-local filter for the images that suffer loss of resolution and feature loss. To mitigate these effects, pixels of the captured image are to be analyzed locally with estimation. NL-SAR does so by the weighting function on the similarities among patches. Thus, offering flexible mechanism for preservation of resolution and fine details. It builds non-local neighborhood for the PL, IN images defined on the similarity of pixel among the patches. After performing several estimations, non-locally best local patch is selected to form an image. By doing so, fluctuations and abnormalities can be handled but there exists room for improvement in resolution preservation estimation algorithms with reference to advancement in radar technology [20]. A transform acts as a function, takes an image as input and produces output image with varying characteristics as per function. Examples of image transforms are wavelet,

principle component analysis etc. Fabrizio Argenti in 2002 approached with translation by undecimated frequency wavelet breakdown for de-speckling of multiplicative noise. In which extended form of mean minimum square error has been applied on multiplicative noise with use of undecimated frequency wavelet. Advantage is of single independent noise by identifying the fact that undecimated frequency wavelet coefficient despeckling is equal to denoising of translation invariant [21]. In addition to the earlier work done in 2002, an enhanced mechanism was proposed including MAP (Maximum A Posteriori) criterion in application with un-decimated wavelet for de-noising of SAR images. The novelty of the work includes exact expression for estimation of Generalized Gaussian distribution without the need for any further assumptions and classification model of wavelet coefficients based on texture energy collected. Benefit of extended algorithm is smoothing of background, preservation of texture, refinement of parameters for estimation irrespective of underlying reflectivity [22].

For the preservation of synthetic aperture radar image edges linlin proposed bandelet transform to detect edge direction along with fuzzy clustering in TIBT (Translation invariant bandelet transform).By the use of Canny operator, edges are detected and removed.Afterwards, combined algorithm of fuzzy clustering and TIBT is applied to de-speckle the image with edge removed. At the end, edges are added back to the denoised image. Results of the experiment depict better visual quality and evaluation indexes outperforms the other methods with no edge preservation [23].For edges refinement and detail preservation, zhang proposed de-speckling algorithm using transforms for SAR images in which curvelet transform and particle swarm optimization techniques have been used that reduce speckle and refined edges details of which in figure 2 lena was subject to test. To non-linearly shrink and stretch the coefficients of curvelet a function for improved gain is put in place that combines speckle reduction with feature enhancement. Benchmark is been set to acquire optimal parameters in gain function. For searching among the finest de-speckle, SAR image enhanced PSO with better learning scheme and mutation operator were introduced. Experiments show that the proposed mechanism outperforms other transforms techniques such as bandelet, curvelet bandelet non adaptive SAR images de-speckling. The algorithm as a whole has high computational cost because of PSO iterative nature which can be reduced if PSO can run in parallel [24]. The filters were useful for noise reduction but were lacking to preserve the relevant features of image that is the textual information. In parallel to filtering techniques, transforms provided edge refinement. So, a lot more can be achieved by combing the two solutions for proposing a new hybrid solution. Sara Parrilli et.al in 2012 proposed a despeckling technique based on non-local filter wavelet transform that forms a basis for todays'' hybrid solutions to despeckling. The proposed performed better in detail preservation and signal to noise ratio by doing the block matching for additive white gaussian noise with iteratively improving the estimator for minimum mean square error. Results of which are shown is figure 3 and 4. Limitations of the proposed solution are ; in actual SAR images with high resolution speckle statistics deviate at time from the solution and quality of SAR images degrade the output for which indicators and ad hoc simulated SAR images solution is been identified for future work [25].

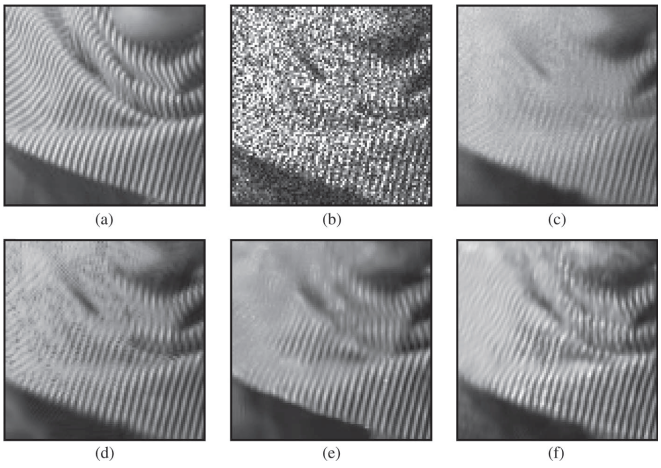

Figure 3: Barbara image zoomed and degraded by single-look speckle noise (a) Clean image (b) Noisy image (c) PPB (d) LPG-PCA (e) SAR- BM3D (f) Clustering based PCA

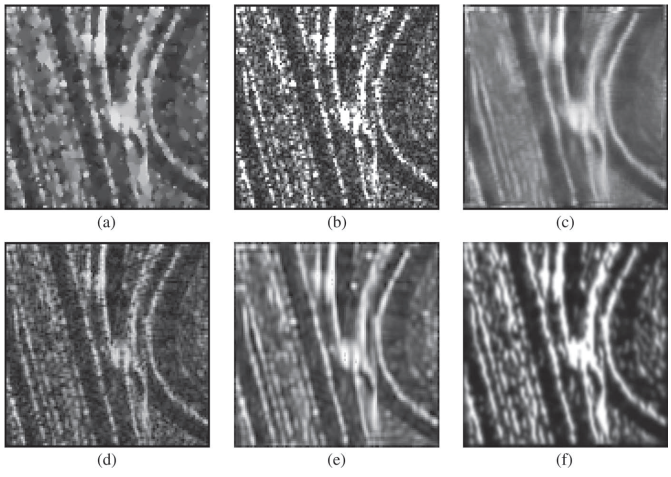

Figure 4: TerraSAR-X SSC image zoomed (126 × 116 pixels) of roads located at the SE of the Macdonald-Cartier Freeway/Allen Road interchange, Toronto, ON, Canada, with L = 1 (a) SRAD (b) Original image (c) PPB (d) LPG-PCA (e) SAR-BM3D (f) Clustering based PCA

Following the work of non-local filters by combining with batch matching algorithm shortcomings are addressed by a fast adaptive non-local despeckling method in 2014 by Davide Cozzolino. Adding to the batch matching 3-d model time critical images are analyzed by an area of variable search size and exploiting the statistics of noise by probabilistic termination to lower computation time. After initial filtering of speckle computation, cost is further reduced by look up tables. Doing so increases performance with lower complexity [26]. With the combination of non-local filters and transforms, better results are obtained in terms of image resolution and detail preservation. The literature of despeckling SAR images is directed towards finding solution in which de-speckling details are preserved. Number of attempts have been put to apply filtering to the feature of image or it can be said more optimistically with the sole reason for

pixel classification in advance when diverse algorithms are applied such as in [30] area under consideration is put to heterogeneity test on variation coefficient. In transforms solutions, same can be adopted when wavelets are used with an appropriate of the textured energy for an AD-Hoc maximum a posteriori [31]. Lately non-local filters gained popularity but possessed same drawbacks of their predecessor that one offering detail preservation and other denoising of the image but each compromising on the other for which alternate adaptive mechanisms have been proposed to overcome the shortcoming [32]. Such as in [16], local selection is been adopted for selection of best parameter is incorporated for denoising. [26] is based on local image estimate in which controlling parameters are adjusted to match the image area under study. To cope with the difference among phase combination to address heterogeneous and homogenous areas stacked processing is done for improved classification [33]. At very small ratio of signal to noise in illustrating the captured image numerous estimators are used to lower the variance factor of the estimate. Lilin clustered the SAR image into disjoint local regions for de-speckling and each region is denoised by applying LMMSE and then the principal component analysis transform. K-mean clustering algorithm is applied by identifying principle components on length criteria. The filtered clusters are joined to form a denoised image [27].

Diego proposed that by doing the pixel wise image classification better results can be achieved that would allow to select an estimator based on the combined characteristics and will be more appropriate. SAR image is divided into regions having homogeneous and geometrical properties for clustering. Several alternate estimates are calculated of the same data and by use of soft classification and de-speckling tools, experiments yield improved results when performed on real-world high-resolution SAR images[28]. Denoising of the SAR images is challenging due to induced phenomena of speckle in which what earlier techniques did not considered was the physical phenomena of electromagnetic scattering in the images that degrades the image quality. Gerardo study of block matching technique for SAR images considers the scattering factor and proposed an extended solution to the original SARBM-3D synthetic aperture radar batch matching with SBSARBM-3D Scattering Based SARBM-3D for speckle reduction without compromising on the details and also reduces the presence of arbitrary effects in homogenous areas of image. The solution leaves room for improvement in the areas of urban and rural environment of peculiar scattering [29]. In a recent study of hybrid de-speckling techniques Alessio et.al proposes an algorithm that requires knowledge about local geography. The solution considers different features of image for de-speckling which are surface description by scattering model, error part acquired by local incidence angle of surface parameters, digital evaluation model and information about errors when digital evaluation model is applied. The need of prior information can be substituted by calculating the local incidence angle directly from SAR data [30-34].

3 Discussion

The goal of this study was to study Hybrid de-speckling techniques for SAR images and explore hybrid solution to improve the results. For which local, non-local, transforms and non-local with transforms are studied and results recorded. Drawback associated with these approaches is introduction of new artifacts to the denoised image. The despeckling techniques have been classified in Table 2 based on the category of solution.

Table 2: Classification and Features of despeckling techniques

	Despeckling Technique	Category
1.	"Sensitivity analysis of a scattering-based …"	Non-Local with Transform
2.	"Scattering-Based SARBM3D …"	Non-Local with Transform
3.	"An iterative SAR image filtering method…"	Non-Local Filters
4.	"SAR despeckling based on soft classification …"	Non-Local with Transform
5.	"Fast adaptive nonlocal SAR despeckling …"	Non-Local with Transform
6.	"SAR image denoising via clustering …"	Non-Local with Transform
7.	" A nonlocal SAR image...on LLMMSE…"	Non-Local with Transform
8.	"SAR image despeckling using Bayesian…"	Non-Local Filters
9.	"An adaptive method of speckle reduction…"	Transforms
10.	"SAR image despeckling using edge …"	Transforms
11.	"Iterative weighted maximum likelihood denoising…"	Non-Local Filters
12.	"Segmentation-based MAP despeckling of SAR …"	Transforms
13.	"A non-local algorithm for image denoising …"	Non-Local Filters
14.	"Speckle removal from SAR images …"	Transforms
15.	"NL-SAR: A unified nonlocal framework . . ."	Non-Local Filter

Non-local filtering approaches in transformed domain outperform local and non-local filters. Their advantages include better detail preservation while speckle suppression. Whereas these approaches are cost inefficient, responsible for inducing some new artifacts to the image being denoised like non-local filters and used lossy transforms which results in information loss. Non-local, Transforms and combined solution has been applied on standard images acquired from the image database of University of Southern California for each image peak signal to noise ratio is calculated and recorded in table 3. The results indicate the performance of the despeckling techniques improves when hybrid solution is applied for denoising.

Table 3: PSNR after applying algorithms on standard images

Image/algos	DCT	PCA	UDWT	SARBM3D
Lena	2.5289	5.8873	5.9175	13.137
Baboon	1.8686	5.3426	5.372	19.4795
House	2.9273	6.3662	6.3984	20.26941
Bridge	2.2273	5.6566	5.687	20.2694
Woman	1.2609	4.1324	4.0921	20.25105

4 Conclusion and Future Work

Remote Image acquisition is an expensive process by both human resources and financially that requires a lot of scientific minds to plan, build and put the carrier in space along with

the mechanism to acquire the images for various purposes in which a country invests its capital to benefit. When these expensive systems are put in place, results which convey precise information about the phenomena are expected so that efforts are justified. Satellites have been successfully revolving around our planet for a long time for information transmission, in past optical sensors were used but due to their limitation of working only in visible spectrum made them obsolete for exploring about phenomena beneath earths' surface and put a constraint on their availability duration. Recent advances in remote sensing systems have introduced a more efficient solution in which Radar functionality can be synthesized and better results can be obtained without the hindrance of the atmospheric factors with all day and night image acquisition. Now by synthesizing antenna having hundreds of long lengths, the active images acquired because of either constructive or destructive combination of received signals speckle occurs. De-speckling, solutions have been provided since 19th century but the ongoing research focuses on the hybrid techniques of those already used to further improve the results. This study focused on the various despeckling solutions presented to cope with the issue and classified the solutions and motivated towards the search for improving the hybrid solution available.

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