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Evaluation of Adaptive Polarimetric Speckle Filters over Agricultural Areas

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Abstract:
Speckle suppression in PolSAR images is an important step for the extraction of meaningful information. Polarimetric speckle filtering is important not only for speckle reduction but also for preserving the polarimetric information and estimate the statistical properties between channels. The fully polarimetric Maximum A Posteriori (MAP) speckle filters namely Wishart Gamma MAP, Wishart DE MAP were evaluated for their efficiency in preserving statistical information in polarimetric SAR image. The filters developed by based on Gamma/Gaussian-distributed scene models reduce speckle noise, while preserving the radar reflectivity, the textural properties, and the spatial resolution, especially in strongly texture SAR images. For the estimating the Statistical information between two filters, five speckle suppression indices namely Equivalent Number of Looks, Speckle Suppression Index, Speckle Suppression and Mean Preservation Index, Edge Enhancing Index, Image Detail Preservation Coefficient were applied on the polarimetric Radarsat-2 quad pol. data over two test sites dominated by agricultural areas. The results show that, Wishart DE MAP yielded better ENL values and all other indices performed similarly with no significant variations.

Key words: *Polarimetric Speckle filters, Speckle assessment indices, Wishart Gamma MAP, Wishart DE MAP*

1. Introduction

Radar waves can interface constructively or destructively to produce light and dark pixels known as speckle noise. Speckle noise is commonly observed in radar sensing systems, although it may appear in any type of remotely sensed image utilizing coherent radiation. Like the light from a laser, the waves emitted by active sensor travel in phase and interact minimally on their way of the target area. After interaction with the target area, these waves are no longer in phase because of the different distances they travel from targets, or single versus multiple bounce scattering. Once out of phase, radar waves can interact to produce light and dark pixels known as speckle noise. Speckle noise in radar is assumed to have multiplicative error model and must be reduced before the data can be utilized otherwise noise is incorporated into and degrades the image quality. Ideally, speckle noise in radar images must be completely removed. Generally speckle noise can be reduced by multi look processing and spatial filtering. While multi look processing is usually done during data acquisition stage, speckle reduction by spatial filtering is performed on the image after it is acquired. The ideal speckle reduction method preserves radiometric information, the edges between different areas and spatial signal variability, i.e., textural information. The spatial filters are categorized into two groups, i.e., non-adaptive and adaptive. Non-adaptive filter take the parameters of the whole image signal into consideration and leave out the local properties of the terrain backscatter or the nature of the sensor. Adaptive filters accommodate changes in local properties of the terrain backscatter well as nature of sensor.

Speckle appear in SAR images due to the coherence interference reflected waves from the many elementary scatters. Speckle reduces the potential of SAR images to be utilized as effective data in remote sensing applications such as classification and segmentation, change detection, biomass estimation and interpretation, due to degradation in appearance, quality and the recorded power of returns (Lee and Pottier, 2009). For this reason, speckle reduction becomes one of the more important tasks in radar remote sensing.

1.1. Polarimetric Speckle filters

Speckle statistics are well described by the Rayleigh speckle model for single polarization SAR imagery. The SAR images with multiplicative noise have the typical characteristic that the local noise standard deviation increases linearly with local mean. For polarimetric data in covariance or coherency matrix forms, the diagonal terms of the matrix have the multiplicative noise characteristics, but the off-diagonal (complex correlation) terms can be modeled by a combination of additive and multiplicative noise model.

The polarimetric speckle filters preserves the statistical correlation between Polarization channels. Theoretically, after filtering, all elements of the covariance matrix will be totally correlated. The statistical relationship between intensities of HH, HV, VV and the correlation coefficient computed from the off-diagonal terms are affected after applying these filters. Consequently, the filtered covariance matrix can no longer be modeled by the complex wishart distribution.

1.1.1. Principle of PolSAR Speckle Filtering

The polarimetric speckle filter should be developed based on the following principle

- To preserve polarimetric properties, each term of the covariance matrix should be filtered in a manner similar to multi look processing by averaging the covariance matrices of the same neighboring pixels. All terms of the covariance matrix should be filtered by the same amount.
- To avoid cross-talk between polarization channels, each element of the covariance matrix has to be filtered independently in the spatial domain.
- To preserve scattering characteristics, edge sharpness and point targets, the filtering has to be adaptive, and the filtering should select neighboring pixels for speckle reduction.

1.1.2. Polarimetric MAP Filters

Two fully polarimetric statistically adaptive speckle filters for single or multi-looks polarimetric SAR data have been developed so far namely the Wishart-Gamma MAP (WG-MAP) filter and the Distribution-Entropy MAP (DE-MAP) filter (Lopes.A,1992). The two filters use the same speckle model: for low look correlation, the conditional probability density function (pdf) of the covariance matrix $\sum_s$ of the speckled measurement is modeled by a complex Wishart law. These filters are suitable for fully polarimetric SAR data and operates under the assumption of target reciprocity (i.e. HV=VH). The output speckle filtered polarimetric vector contains all the polarimetric information required further computation of phase differences, degree of coherence, polarimetric synthesis, polarimetric indices, etc.

1.1.2.1 Wishart Gamma MAP Filter

In this filter, A Priori knowledge about the scene is modeled by a Gamma distributed scalar parameter **μ,** equal to the normalized number of scatterers by resolution cell. This model is suited to restore most textured scenes at the usual space borne and airborne-civilian SAR resolutions, when the detected intensity channels can be assumed as being K-distributed. This filter is best performing in presence of regular texture or moderate relief.

1.1.2.2. Wishart Distribution Entropy MAP Filter

In this filter, A Priori knowledge about the scene is modeled by the probability density function of the textural parameter **μ,** designed **as** to have the entropy **S=S(μ).** This is a Maximum Entropy constraint that optimizes the adaptive filter for the restoration and the enhancement of very strong and/or mixed textures, possibly at all SAR resolutions. This filter is best performing in presence of strong mixed texture or strong relief. (Jain, 1989)

1.3. Speckle Assessment indices

There are several methods to assess the filter image quantitatively according to different aspects such as noise reduction, edge preservation, feature preservation (Sheng and Xia, 1996). The different assessment methods should be used to find the optimum tradeoff among the different aspects of image quality assessment (Qiu et al., 2004).

1.3.1. Equivalent Number of Looks (ENL)

Measuring the Equivalent Numbers of Looks (ENL) over a uniform image region is a good approach for estimating the speckle noise level in a SAR image. A larger of the value of ENL usually corresponds to a better quantitative performance. The value of ENL also depends on the size of the tested region, theoretically a larger region will produces a higher ENL value than over a smaller region but due to the difficulty in identifying uniform areas in the image, dividing the image into smaller areas, obtain the ENL for each of these smaller areas and finally take the average of these ENL values is considered. The formula for the ENL calculation is given in as (Gagnon and Jouan, 1997):

$$\text{ENL} = \left(\frac{mean}{standard\ deviation}\right)^2$$

The higher ENL value for a filter, the higher efficiency in smoothing speckle noise over homogeneous areas.

1.3.2. Speckle Suppression Index (SSI)
This index is based on the equation as follows:

$$SSI=\frac{\sqrt{var\ (I_f)}}{mean\ (I_f)} \times \frac{mean\ (I_o)}{\sqrt{var\ (I_o)}}$$

Where I_f = filtered image
I_o = noisy image
This index tends to be less than 1 if the filter performance is efficient in reducing the speckle noise (Sheng and Xia, 1996).

1.3.3. Speckle Suppression and Mean Preservation Index (SMPI)
ENL and SSI are not reliable when the filter overestimates the mean value. In such cases an index called Speckle Suppression and Mean Preservation Index (SMPI) is a better indicator. The equation of this index is as follow:

$$SMPI= Q \times \frac{\sqrt{var\ (I_f)}}{\sqrt{var\ (I_o)}}$$

And Q is calculated as follows:

$$Q= R+\left|mean\ (I_o) - mean\ (I_f)\right|$$

Where

$$R= \frac{Max\ (mean(I_f)) - Min\ (mean(I_f))}{mean\ (I_o)}$$

According to this index, lower values indicate better performance of the filter in terms of mean preservation and noise reduction.

1.3.4. Edge-Enhancing Index (EEI)
This value indicates how much a filter is able to preserve the edge areas and is defined as(Sheng and Xia, 1996):

$$EEI=\frac{\Sigma\left|DN_{1f}-DN_{2f}\right|}{\Sigma\left|DN_{1o}-DN_{2o}\right|}$$

Where,
DN_{1f} and DN_{2f} = filtered values of the pixels on either side of the edge
DN_{1o} and DN_{2o} = original values of the corresponding pixels
EEI values are usually less than 1 and higher values indicate better edge preservation capability.

1.3.5. Image Detail-Preservation Coefficient (IDPC)
The correlation coefficient between original image and filtered image over fine details such as point scatterers is defined as IDPC (Sheng and Xia, 1996).

2. Methodology
In this study, the C-band RADARSAT-2, SLC in Fine quad pol data (Table.1) of Guntur and Anantapur Districts in Andhra Pradesh were used. The study area were mostly covered with agricultural crops like Cotton, Rice, Chilies' in Guntur; mostly groundnut in Anantapur apart from fallow fields in these test sites.
SARscape software was used for processing of the data sets. The Wishart Gamma MAP, Wishart Distribution Entropy MAP filters with different window sizes (3*3, 5*5 and 7*7) were applied on these data sets. To evaluate the effectiveness of these algorithms five speckle assessment indices namely Equivalent Numbers of Looks (ENL)**,** Speckle Suppression Index (SSI), Speckle Suppression and Mean Preservation Index (SMPI), Edge-Enhancing Index (EEI) and Image Detail-Preservation Coefficient (IDPC).Both visual and digital analysis tools were used to assess the speckle filters. For Visual comparison, the sub area of 512x512 pixels were selected and compared for feature depiction.

3. Results and Discussion
Both visual and digital analysis tools were used to assess the speckle filters
- Visual comparison: The sub area of 512x512 dimensions was sleeted for comparison. The HH, HV &VV Quad pol. data over parts of Guntur district for the date 26Oct10 images filtered with Wishart Gamma Map & Wishart Distribution Entropy Map with different window sizes (3x3, 5x5, 7x7) were shown in figure.1. With increasing window size, smoothing of the feature observed. (Figure.1)

- Digital analysis: The scene statistics- Max, Min, Mean and St. Deviation of both test sites (Table.2) reveals that, range has increased in Wishart Gamma Map (3x3, 5x5) and Wishart DE Map (3x3) in Guntur test site for the year 2011 and more or less constant in other treatments. Similar results were observed in 2010.

In order to compare statistical behavior of Wishart Gamma MAP, Wishart DE MAP different window sizes of Polarimetric speckle filters, different speckle suppression indices calculated. These are shown below Table.3

As above table shows, the performance of Wishart Gamma MAP, Wishart DE MAP filters are very good for suppressing the speckle noise over the homogeneous areas, Wishart DE MAP filter shows little higher ENL indicates higher efficiency in smoothing speckle noise over homogeneous areas, both filters shows Higher ENL value was observed in cross polarizations than in like polarizations and by increasing window size ENL value was decreasing, SSI shows less than one in all window sizes for two filters and SMPI Index showed lower value in 3x3 window size compared to other window sizes.

- **Edge Preservation:** In order to use EEI index, the edge between different crops was selected. Wall to wall ground truth was collected synchronous to satellite date of pass was used for the EEI. The results of this index for the two filters shows the best algorithm performance for the edge preservation were observed in VV polarization in all window sizes. (Figure2 & 3)
- **Preservation of Details:** More than one thousand pixels representing significant features were selected separately over the two images and, the correlation between filtered and original images over the selected pixels was calculated. The best feature preservation was performed by both filters in different window sizes; their index values show no variation for all features. IDPC calculated in both filters that is shown in Figure.4&5

The Figure.4&5 showed that there is no significant difference in magnitude of all indices. Hence, there is no significant change between two filters and it preserves the correlation between channels. For our study, these two filters were found to be performing uniformly in reducing speckle noise.

4. Conclusion

The evaluation of Polarimetric speckle filters was carried out with the objective of the preservation of the polarimetric information and statistical properties by fully polarimetric adaptive speckle MAP filters (Wishart Gamma MAP, Wishart Distribution Entropy MAP). For the evaluation of these filters, five speckle assessment indices ENL, SSI, SMPI, EEI and IDPC were computed. The higher ENL values that mean higher efficiency in smoothing speckle noise has been observed in Wishart DE MAP filter than Wishart Gamma MAP filter. The indices SSI, SMPI, EEI and IDPC showed similar results for both filters and there are no significant variations. It was concluded that there is no significant difference between the performances of the two filters studied, while preserving the correlation between channels and retaining all the polarimetric information required further computation of phase differences, degree of coherence, polarimetric synthesis, polarimetric indices, etc.

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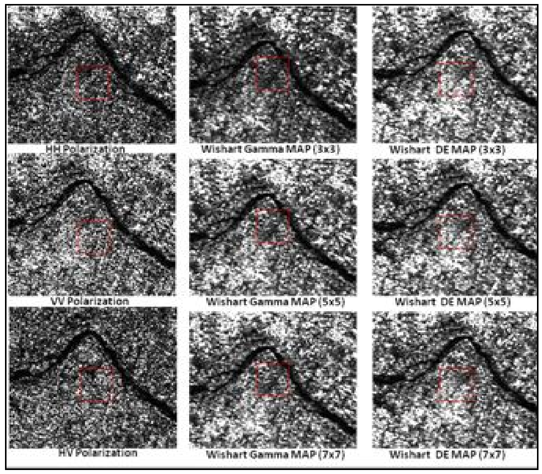

Figure 1: Manifestation of different features in Raw and Wishart Gamma MAP and Wishart DE MAP

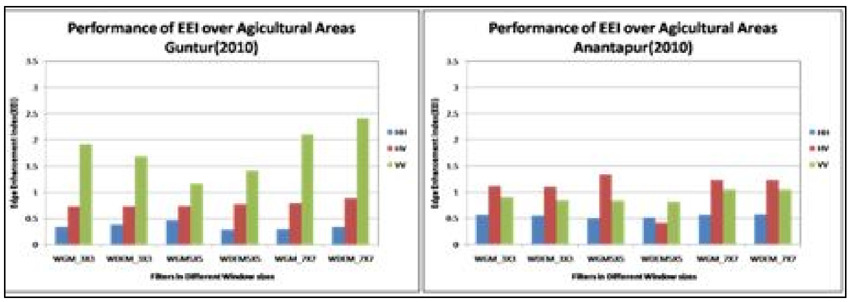

Figure.2.EEI in Wishart Gamma MAP, Wishart DE MAP (2010) filters with different window sizes and Polarizations

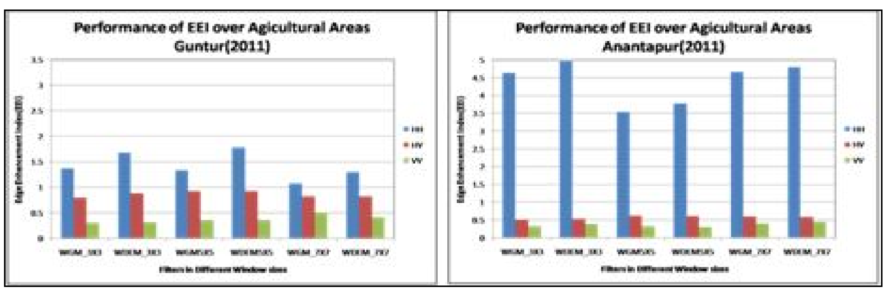

Figure.3.EEI in Wishart Gamma MAP, Wishart DE MAP (2011) filters with different window sizes and Polarizations

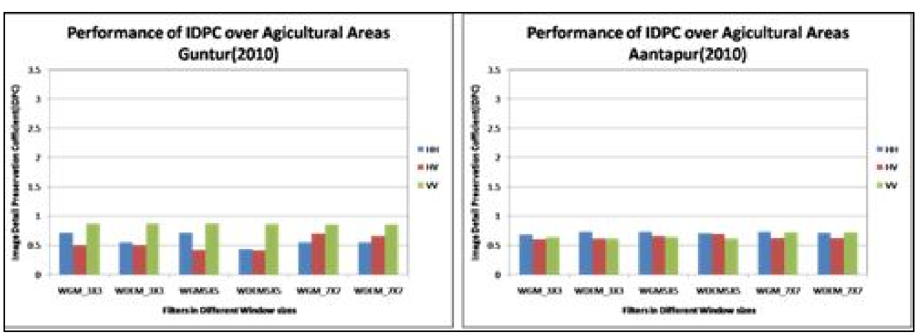

Figure.4 IDPC in Wishart Gamma MAP, Wishart DE MAP (2010) with different window sizes and Polarizations

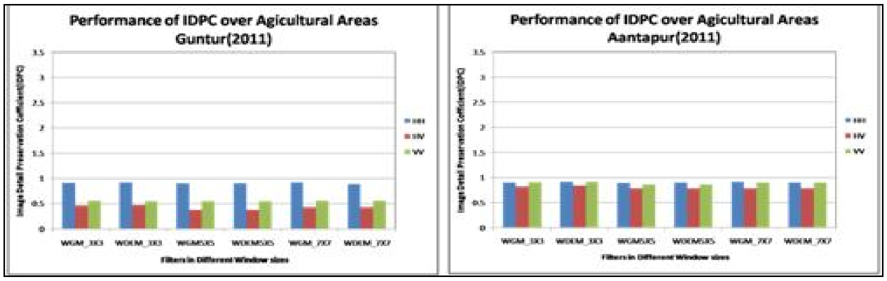

Figure.5. EEI in Wishart Gamma MAP, Wishart DE MAP (2011) with different window sizes and Polarizations

Test site	Satellite/ Sensor	Date of Pass	Incidence Angle	Date of pass	Incidence Angle
year		2010		2011	
Guntur	Radarsat2_FQ	Oct26	34.12	Oct21	34.62
Anantapur	Radarsat2_FQ	Sep04	25.49	Aug20	39.08

Table 1: Details of Data used

Guntur_2011							Anantapur_2011					
Filter	**Polarization**	**Min**	**Max**	**Mean**	**Std**		**Filter**	**Polarization**	**Min**	**Max**	**Mean**	**Std**
Raw	HH	0	93.023	0.097	0.645		**Raw**	HH	0	101.023	0.063	0.292
	HV	0	92.247	0.01	0.043			HV	0	4.005	0.009	0.019
	VV	0	92.989	0.077	0.404			VV	0	84.066	0.057	0.151
Wishart Gamma Map(3x3)	HH	0	107.862	0.195	0.746		**Wishart Gamma Map(3x3)**	HH	0	100.241	0.129	0.325
	HV	0	52.126	0.021	0.045			HV	0	3.115	0.017	0.017
	VV	0	92.789	0.154	0.457			VV	0	64.955	0.116	0.144
Wishart Gamma Map(5x5)	HH	0	92.967	0.195	0.783		**Wishart Gamma Map(5x5)**	HH	0	106.849	0.128	0.342
	HV	0	69.349	0.02	0.049			HV	0	3.115	0.017	0.017
	VV	0	92.789	0.153	0.483			VV	0	73.139	0.116	0.151
Wishart Gamma Map(7x7)	HH	0	93.011	0.196	0.832		**Wishart Gamma Map(7x7)**	HH	0	101.023	0.129	0.362
	HV	0	69.349	0.021	0.049			HV	0	4.005	0.017	0.017
	VV	0	92.989	0.154	0.52			VV	0	77.17	0.116	0.156
Wishart DE Map(3x3)	HH	0	92.967	0.199	0.754		**Wishart DE Map(3x3)**	HH	0	144.668	0.132	0.33
	HV	0	52.126	0.021	0.046			HV	0	3.115	0.018	0.017
	VV	0	92.789	0.157	0.462			VV	0	64.955	0.119	0.145
Wishart DE Map(5x5)	HH	0	92.967	0.199	0.789		**Wishart DE Map(5x5)**	HH	0	100.241	0.131	0.343
	HV	0	69.349	0.021	0.049			HV	0	3.115	0.018	0.017
	VV	0	92.789	0.157	0.487			VV	0	66.811	0.118	0.151
Wishart DE Map(7x7)	HH	0	93.011	0.2	0.834		**Wishart DE Map(7x7)**	HH	0	101.023	0.132	0.362
	HV	0	69.349	0.021	0.049			HV	0	4.005	0.018	0.017
	VV	0	92.989	0.158	0.521			VV	0	77.17	0.119	0.156

Table 2: Scene statistics of different Raw and Speckle filtered images

Guntur_2011						Anantapur_2011				
Filter(3×3)	**Image**	**ENL**	**SSI**	**SMPI**		**Filter(3×3)**	**Image**	**ENL**	**SSI**	SMPI
Wishart Gamma Map	HH	2.017	0.045	0.121		**Wishart Gamma Map**	HH	2.502	0.055	0.099
	HV	2.601	0	0.1			HV	2.013	0	0.112
	VV	1.747	0.006	0.096			VV	2.473	0.009	0.098
Wishart Distribution Entropy Map	HH	2.207	0.045	0.115		**Wishart Distribution Entropy Map**	HH	2.581	0.057	0.096
	HV	2.745	0	0.1			HV	2.093	0	0.112
	VV	1.823	0.007	0.095			VV	2.661	0.009	0.095
Filter(5×5)	Image	ENL	SSI	SMPI		**Filter(5×5)**	Image	ENL	SSI	SMPI
Wishart Gamma Map	HH	1.897	0.045	0.125		**Wishart Gamma Map**	HH	2.282	0.057	0.105
	HV	2.411	0	0.104			HV	1.606	0	0.125
	VV	1.485	0.007	0.104			VV	2.401	0.009	0.099
Wishart Distribution Entropy Map	HH	2.038	0.045	0.12		**Wishart Distribution Entropy Map**	HH	2.371	0.058	0.102
	HV	2.49	0	0.105			HV	1.67	0	0.124
	VV	1.605	0.007	0.101			VV	2.556	0.009	0.096
Filter(7×7)	Image	ENL	SSI	SMPI		**Filter(7×7)**	Image	ENL	SSI	SMPI
Wishart Gamma Map	HH	1.829	0.045	0.128		**Wishart Gamma Map**	HH	2.037	0.06	0.111
	HV	2.232	0	0.108			HV	1.617	0	0.124
	VV	1.442	0.007	0.106			VV	2.348	0.009	0.1
Wishart Distribution Entropy Map	HH	1.971	0.046	0.122		**Wishart Distribution Entropy Map**	HH	2.256	0.059	0.105
	HV	2.382	0	0.107			HV	1.729	0	0.121
	VV	1.578	0.007	0.102			VV	2.437	0.009	0.099

Table 3: Speckle Assessment indices (ENL, SSI and SMPI) in Wishart Gamma MAP and Wishart DE MAP filters