A COMMON EVALUATION APPROACH TO SMOOTHING AND FEATURE PRESERVATION IN SAR IMAGE FILTERING

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Abstract

Several SAR image filtering approaches have been proposed. Each approach uses a different method to estimate the true value of pixels. A good filter should reduce the speckle noise while preserving the edges. In this paper, we present a new evaluation method for SAR image filtering. It is based upon the evaluation of the estimator bias and dispersion. Those parameters indicate the agreement between the estimator value and the true mean value. We show that the estimator bias and dispersion can be used to evaluate edge preserving filters. The bias near an edge is related to the blurring and displacement of the edge. The distance from edges and the contrast of edges are important parameters of the evaluation procedure. A Monte Carlo simulation approach is used and several popular filters are compared.

I. INTRODUCTION

Radar images are characterized by the presence of speckle which is a multiplicative noise. The model of the radar signal is given by [5]:

$$I(x, y) = R(x, y) \times U(x, y)$$

where (x,y) represents the spatial coordinates of a point in the image. I(x,y) is the observed signal intensity or power. R(x,y) is the terrain reflectivity or the average backscattering signal. The filtering process consists in the estimation of R(x,y) from I(x,y). U(x,y) is a multiplicative speckle noise statistically independent of R(x,y) and with a unit mean value.

The filtering of SAR images has two conflicting goals: the removal of speckle noise by smoothing and the preservation of image features such as specular spots, linear features and region edges. An intensity SAR image can be view as a stochastic process with two components, R and U. The image filtering consists then in the estimation of R, denoted $\hat{R}$. A good filter should maintain the signal mean value and reduce the speckle. Hence, the estimator should have no bias, and the dispersion of its values around the mean should be small. The smoothing aspect is required for the filtering of homogeneous areas. In heterogeneous areas, the filter should preserve the features. The evaluation of the preservation of features such as lines and edges is complex. To simplify the analysis, a step edge model is usually employed. Different methods have been proposed to evaluate the edge blurring and displacement. In this paper, we present a new evaluation method for SAR image filtering. We show that the estimator bias and dispersion can be used to evaluate edge preserving filters. The bias near an edge is related to the blurring and displacement of the edge. The approach is used to evaluate the Box filter, the Lee filter [2], the Kuan filter [4], the Gamma filter [5] and a new filter, the Least Commitment Filter (LCF) [1]. The results agree with previous ones and show the advantages and limitations of each filter.

II. THE EVALUATION APPROACH

Image filtering can be viewed as an estimation problem. It can be evaluated by comparing the estimated value, defined by $\hat{R}(x,y)$, with the true value R. In statistics, the quality of estimators is measured by the bias and the dispersion around the mean value. The bias is the difference between the mean value of the estimator, $E(\hat{R})$, and the true mean value R. The variance of the estimator, $Var(\hat{R})$, is a measure of the dispersion around the mean value. In SAR image applications, the variation coefficient, $C = \sigma / \mu$, is used instead of the variance.

The bias and the dispersion are generally used for the evaluation of the estimator in homogeneous areas. It is known that the best estimator of the mean is the average of the sample values. In image filtering, this corresponds to the Box filter which calculates the average over a NxN window. In this case, the bias should be null and the dispersion reduced by N. The variation coefficient of the estimator, $C_{\hat{R}}$, is related to the variation coefficient of the speckle, C_U, and to the window size N [5]:

$$C_{\hat{R}} = C_U / N .$$

The filtering consists in the smoothing of data and the amount of smoothing is related to the reduction of the variance or variation coefficient.

The evaluation of filters for heterogeneous areas has not yet received a uniform and scientific sound definition. The main aspect is that an area contains at least two distinct regions with distinct R values and that the filtering process blurs the edges between them. A good filter should preserve these edges. Evaluation techniques can use the slope at edge points as to estimate the introduced blur [6]. The displacement of edge positions is also employed.

We propose to use the bias and the dispersion of the estimator to evaluate the preservation of image features (edges). The blurring or displacement of edges introduces an important bias in the estimator. The bias value is larger at edge point and decreases with the distance from the edge. Edge displacement produces an asymmetric decrease of the bias. Stronger blurring results in a slower decrease of the bias. Therefore, the bias contains the main information about the edge preservation.

We should also consider the reduction of the variation coefficient of the estimator, $C_{\hat{R}}$. Hence, some techniques do not perform filtering at edge points in order to reduce the bias. However, there is then no reduction of the variation coefficient, $C_{\hat{R}} = C_U$. Filter design can thus be viewed as a tradeoff between a small bias and a reduction of the variation coefficient.

The evaluation should also consider the contrast between regions at edge points. Adaptive filtering techniques try to detect the presence of edges, which is difficult when the contrast is low. Real data contains regions of varying sizes and contrasts, and good filters should be able to process correctly these different cases.

III. EXPERIMENTAL PROCEDURE AND EVALUATION RESULTS

A Monte Carlo approach is used for the evaluation of the estimator bias and dispersion for different filters. A set or sequence of independent random images, $I_t(x,y)$, should be generated with known region reflectivity R(x,y). The images can be viewed as the outcomes of an ergodic stochastic process. Thus, the average on image sequence numbers can be replaced by the average over an image area. In homogenous images, we can use the average over a window. For pixels close to edges, the average should be performed only on pixels located at the same distance from edges.

In the current filter evaluation, 4-look images are generated. We first evaluate the filters with a homogeneous image (uniform reflectivity). Then, we use images with two distinct reflectivity areas separated by a step edge. We examine the cases of high contrast and low contrast between the two regions. The evaluated filters are not affected by edge orientation; the same results should be obtained for any direction. A vertical edge is used. Pixels in a same column are located at the same distance from the edge. The calculation of estimator bias and dispersion are therefore performed on one column at a time.

We calculate the mean value and the variation coefficient for each column of the filtered images. The bias is calculated as the difference between the calculated mean value and the true mean value. There is a relation between the variation coefficient and the number of looks,

$C_U \approx 1$ / . The Equivalent Number of Looks, ENL = 1 / C^2, is thus often used instead of the variation coefficient C.

In this section, the Lee filter [2], the Kuan filter [4], the Gamma filter [5] and the LCF filter [1] are evaluated using three simulated SAR images. The first image corresponds to a homogeneous area, the second contains two distinct areas with a high contrast and the third two areas with a low contrast. These SAR images are 4-look images of 500x500 pixel.

1) Evaluation with a homogeneous area

We use a simulated SAR image containing only one homogeneous area. The amplitude mean value, the variation coefficient and the ENL value calculated from the original image are shown in Table 1. Each filter is tested on this image and the bias (amplitude), the variation coefficient and the ENL value are calculated from the filtered image. Different window sizes are used. The results are shown in Table 2. We see that ENL values increase (and $C_{\hat{R}}$ decrease) with window size. The ENL value is an indication of the amount of smoothing performed. In homogeneous areas, the Box filter is the ideal filter: the ENL value is large and the bias is small. Generally, we consider that all filters produce good results over a homogeneous area. We can see that:

- The performances of the Lee filter and the Kuan filter are similar.
- The Gamma filter produces a better noise reduction than the Lee filter and the Kuan filter.
- The Gamma filter and the LCF filter have a larger bias then the other filters.

Mean	$C_I = C_U$	ENL
22.70	0.499	4.01

Table 1: Parameters of the homogeneous image.

	Window	3 x 3	5 x 5	7 x 7	9 x 9	11 x 11
Box	Bias	+0.001	+0.001	+0.002	+0.003	+0.003
	$C_{\hat{R}}$	0.190	0.117	0.085	0.067	0.056
	ENL	27	72	138	218	316
Lee	Bias	-0.010	-0.010	-0.010	-0.015	-0.016
	$C_{\hat{R}}$	0.224	0.146	0.109	0.088	0.076
	ENL	19	46	82	126	172
Kuan	Bias	-0.002	-0.007	+0.010	+0.010	+0.010
	$C_{\hat{R}}$	0.302	0.182	0.119	0.095	0.098
	ENL	10	30	69	110	162
Gamma	Bais	-0.180	-0.172	-0.154	-0.121	-0.096
	$C_{\hat{R}}$	0.226	0.143	0.103	0.081	0.068
	ENL	19	48	93	149	214
LCF	Bias	+0.052	+0.113	+0.131	+0.142	+0.117
	$C_{\hat{R}}$	0.208	0.138	0.107	0.090	0.080
rr=0.80	ENL	23	52	87	121	153

Table 2: The evaluation results for the homogeneous image.

2) Evaluation with two high contrast areas

We now use a simulated SAR image containing two distinct regions with a high contrast. The two regions are separated by a vertical edge. The region intensity mean ratio is 7.0 and the amplitude ration is 2.65. The amplitude mean values, the variation coefficients and the ENL values for the two areas are shown in Table 3. A window size of 11x11 is used for all filters. For each filter, we calculate the mean, the bias, the variation coefficient and the ENL value for each column. The results of 12 columns are shown in Table 4, i.e., 6 columns on both sides of the edge. The central columns are the closer to the edge.

These results show the tradeoff between the bias and the dispersion of the estimator. The Box filter produces the smallest dispersions and the largest ENL values. The reduction of the dispersion is a function of the window size and not of the distance from the edge. As expected, the Box filter also produces the largest bias, particularly close to the edge. This corresponds to the blurring of the edge.

The Gamma filter shows completely different results. The small ENL values show that no filtering has been done near the edge. The filter has detected the presence of the edge and preserved the original pixel values to avoid the blurring of the edge. This produces a low bias. Preserving the original pixel values means that the bias is low and the noise is not reduced.

The results of the Lee filter and the Kuan filter are midway between those of the Box filter and the Gamma filter. The Lee filter has larger bias and ENL values than the Gamma filter, and the values for the Kuan filter are even larger. There is more blurring and noise reduction.

The best results are produced by the LCF filter. The bias is small, meaning a small edge blurring. For this aspect, the LCF filter is similar to the Gamma filter. However, the LCF filter does noise reduction, producing larger ENL values. The ENL values are even larger than those of the Kuan and the Lee filter, and this is obtained with almost no blurring. This shows that the LCF filter avoids edge blurring while performing noise reduction. This correspond to a different tradeoff between the bias and the dispersion of the estimator. The LCF filter obtains interesting values for both at the same time.

Image	Area 1			Area 2		
	Mean	$C_I = C_U$	ENL	Mean	$C_I = C_U$	ENL
high contrast	9.64	0.502	3.96	25.51	0.504	3.93
low contrast	11.20	0.501	3.98	14.14	0.497	4.04

Table 3: Parameters of the images with two distinct areas.

Filter		left col.						right col.					
Box	Mean	9.68	11.04	12.48	13.88	15.27	16.69	18.16	19.57	21.04	22.48	23.93	25.33
	Bias	+0.04	+1.40	+2.84	+4.24	+5.63	+7.05	-7.33	-5.94	-4.47	-3.03	-1.58	-0.18
	$C_{\hat{R}}$	0.064	0.058	0.061	0.066	0.066	0.062	0.059	0.060	0.058	0.060	0.057	0.059
	ENL	239	296	262	225	224	252	279	273	289	270	303	277
Lee	Mean	9.97	10.22	10.47	11.24	11.76	12.63	23.75	24.12	24.28	24.57	25.37	26.13
	Bias	+0.33	+0.58	+0.83	+1.60	+2.12	+2.99	-1.76	-1.39	-1.23	-0.94	-0.14	+0.62
	$C_{\hat{R}}$	0.074	0.393	0.383	0.326	0.258	0.241	0.407	0.354	0.319	0.230	0.149	0.064
	ENL	180	6	6	9	14	17	6	8	9	18	44	238
Kuan	Mean	9.97	10.70	11.37	12.37	13.13	14.15	23.17	23.69	24.04	24.48	25.33	26.13
	Bias	+0.33	+1.06	+1.73	+2.73	+3.49	+4.51	-2.34	-1.82	-1.47	-1.03	-0.18	+0.62
	$C_{\hat{R}}$	0.071	0.294	0.267	0.222	0.174	0.159	0.348	0.299	0.265	0.189	0.125	0.062
	ENL	198	11	14	20	32	39	8	11	14	27	63	258
Gamma	Mean	9.92	9.71	9.55	9.88	9.65	9.58	24.84	25.25	24.72	23.19	24.58	26.02
	Bias	+0.28	+0.07	-0.09	+0.24	+0.01	-0.06	-0.67	-0.26	-0.79	-2.32	-0.93	+0.51
	$C_{\hat{R}}$	0.074	0.503	0.525	0.487	0.455	0.514	0.509	0.487	0.510	0.240	0.134	0.065
	ENL	180	4	4	4	4	4	4	4	4	17	54	232
LCF rr=0.80	Mean	9.98	9.97	9.98	10.04	10.06	10.01	25.45	25.64	25.92	25.91	25.96	25.93
	Bias	+0.34	+0.33	+0.34	+0.40	+0.42	+0.37	-0.06	+0.13	+0.41	+0.40	+0.45	+0.42
	$C_{\hat{R}}$	0.074	0.093	0.104	0.121	0.099	0.114	0.176	0.138	0.119	0.106	0.101	0.110
	ENL	177	114	91	68	100	75	31	52	70	87	97	81

Table 4. The evaluation results for the high contrast image.

3) Evaluation with two low contrast areas

We now use a simulated SAR image composed of two distinct regions with a low contrast. The parameters of the image are shown in Table 3. The region intensity mean ratio is 1.6 and the amplitude ration is 1.26. A window size of 11x11 is used. For each filter, we calculate the means, the bias, the variation coefficients and the ENL values for 12 columns. The results are listed in Table 5.

Real images contain regions with varying contrasts. A good filter should be able to take account of those differences. Unfortunately, we expect that adaptive filter for SAR images will not be able to correctly detect the presence of edges when the contrast is low. This is what is showed by the following results. The Lee, Kuan and Gamma filters do lest filtering than the Box filter but the differences are small. The noise reduction and edge blurring are important. The LCF filter produces better results only when the relative range parameter (rr) is small.

Filter		left col.						right col.					
Box	Mean	11.17	11.27	11.54	11.78	12.01	12.26	12.54	12.79	13.07	13.33	13.60	14.06
	Bias	-0.03	+0.10	+0.34	+0.58	+0.81	+1.06	-1.60	-1.17	-1.07	-0.81	-0.54	-0.07
	$C_{\hat{R}}$	0.064	0.056	0.055	0.058	0.059	0.055	0.053	0.054	0.054	0.057	0.054	0.059
	ENL	239	318	319	296	285	322	349	337	341	302	333	277
Lee	Mean	11.29	11.61	11.58	12.10	12.26	12.45	13.19	13.37	13.59	13.79	14.06	14.28
	Bias	+0.09	+0.41	+0.65	+0.80	+1.06	+1.25	-0.95	-0.77	-0.55	-0.35	-0.08	+0.14
	$C_{\hat{R}}$	0.074	0.089	0.098	0.112	0.098	0.105	0.139	0.118	0.106	0.085	0.073	0.064
	ENL	180	126	103	79	103	90	51	70	87	135	183	238
Kuan	Mean	11.30	11.61	11.87	12.13	12.30	12.51	13.16	13.35	13.58	13.79	14.06	14.27
	Bias	+0.10	+0.41	+0.67	+0.93	+1.10	+1.31	-0.98	-0.79	-0.56	-0.35	-0.08	+0.13
	$C_{\hat{R}}$	0.071	0.078	0.085	0.096	0.086	0.089	0.117	0.101	0.091	0.076	0.068	0.062
	ENL	198	152	137	146	174	158	117	111	119	140	160	258
Gamma	Mean	11.24	11.48	11.67	11.88	12.04	12.21	12.91	13.12	13.41	13.65	13.97	14.22
	Bias	+0.04	+0.28	+0.47	+0.68	+0.84	+1.01	-1.23	-1.02	-0.73	-0.49	-0.17	+0.08
	$C_{\hat{R}}$	0.073	0.089	0.099	0.106	0.104	0.114	0.113	0.103	0.089	0.078	0.068	0.064
	ENL	185	124	101	87	91	75	78	93	125	164	212	238
LCF rr=0.60	Mean	11.16	11.01	11.14	11.46	11.66	11.94	13.05	13.40	13.78	13.80	13.98	14.09
	Bias	-0.04	-0.19	-0.06	+0.26	+0.46	+0.74	-1.09	-0.74	-0.36	-0.34	-0.16	-0.05
	$C_{\hat{R}}$	0.196	0.170	0.198	0.187	0.196	0.230	0.230	0.190	0.186	0.180	0.210	0.156
	ENL	26	33	25	28	26	19	19	27	29	30	22	40
LCF rr=0.70	Mean	11.25	11.30	11.43	11.62	11.89	12.18	12.97	13.28	13.64	13.80	14.01	14.11
	Bias	+0.05	+0.10	+0.23	+0.42	+0.69	+0.98	-1.17	-0.86	-0.50	-0.34	-0.13	-0.03
	$C_{\hat{R}}$	0.099	0.107	0.120	0.132	0.123	0.160	0.150	0.132	0.124	0.113	0.112	0.119
	ENL	101	86	68	56	65	39	44	46	64	77	80	70
LCF rr=0.80	Mean	11.20	11.38	11.68	12.04	12.23	12.45	13.00	13.16	13.38	13.59	13.88	14.08
	Bias	0.00	+0.18	+0.48	+0.84	+1.03	+1.25	-1.14	-0.98	-0.76	-0.55	-0.26	-0.06
	$C_{\hat{R}}$	0.119	0.120	0.131	0.136	0.113	0.116	0.091	0.091	0.096	0.098	0.115	0.126
	ENL	70	70	70	58	78	74	119	118	107	102	75	63

Table 5. The evaluation results for the low contrast image.

IV. CONCLUSION

A good filter should reduce the speckle noise while preserving the edges. This paper presents a new approach to evaluate SAR image filters. The used criteria are the bias and the dispersion of the estimator. The bias is related to the preservation of the image definition (blurring), and the dispersion is a measure of the speckle reduction. We have tested popular filtering techniques using artificial SAR images. We have examined the filter results inside homogeneous areas, near high contrast edges and near low contrast edges. For high contrast edges, the results show that the Gamma filter avoids the edge blurring by preserving the original pixel values. The LCF filter also avoids the edge blurring while doing noise reduction.

The proposed evaluation approach is powerful and provides useful information about the filter operations. We are considering the utilisation of different parameter values for the experiments. We will examine smaller window sizes, different contrast values and a lower value for the rr parameter of the LCF filter (a 0.5 value will be more appropriate for a 4-look image).

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