A COMPARATIVE SENSITIVITY ANALYSIS OF SCATTERING-BASED DESPECKLING ALGORITHMS

Gerardo Di Martino, Alessio Di Simone, Antonio Iodice, Daniele Riccio, Giuseppe Ruello

Università di Napoli Federico II, Via Claudio 21, 80125, Naples, Italy

ABSTRACT

Synthetic aperture radar (SAR) image interpretation and analysis are heavily affected by speckle noise typical of coherent acquisition systems. Very recently, a novel despeckling approach based on the exploitation of a priori information about the scattering behavior of illuminated surface has been presented. The new scattering-based algorithms, named SB-PPB and SB-SARBM3D, represent a scattering-oriented version of the PPB and SARBM3D pre-existing algorithms. In this paper, a comparative sensitivity analysis of the aforementioned despeckling algorithms is conducted by means of SAR image simulation tools. In particular, first, the sensitivity of the filters against the electromagnetic scattering behavior of the illuminated surface is analyzed. Then, the role of the digital elevation model resolution and the coregistration step is also investigated.

Index Terms— Synthetic Aperture Radar, despeckling, electromagnetic scattering, image processing, fractals, nonlocal means.

1. INTRODUCTION

Due to the coherent acquisition process, synthetic aperture radar (SAR) images are affected by the multiplicative noise, called speckle. To improve the understandability and to support the retrieval of information from SAR data, a despeckling pre-processing step is recommended for most applications. In the last three decades, several approaches and methods have been developed and assessed. The heterogeneity, i.e., statistical non-stationarity, of SAR images makes the nonlocal means one of the most effective approaches. Within this framework, the despeckling process is based on the definition of a proper similarity criterion related to the peculiarities of SAR data statistics. Very recently, a novel nonlocal approach to the despeckling problem based on electromagnetic scattering laws has been presented and implemented in different algorithms [1], [2], [3]. The new approach relies on the introduction of a physical-based similarity criterion to reduce speckle effects in SAR images of natural surfaces. In particular, the scattering behavior of the illuminated surface is properly modeled via fractal models and is used as a priori information in the similarity criterion. The new scattering-based algorithms, namely SB-PPB and SB-SARBM3D, represent a modified version of the PPB and SARBM3D pre-existing algorithms originally presented in [4] and [5], respectively, in which the scattering behavior of the resolution cell is modeled via the Small Perturbation Method (SPM) and taken into account in the despeckling chain. The exploitation of the a priori scattering information has proved to improve the overall performance of the original algorithms in terms of both speckle reduction and detail preservation [2], [3].

In this paper, we provide a comparative experimental sensitivity analysis of the SB-PPB and SB-SARBM3D despeckling filters against:

- the scattering model describing the surface;
- misalignments in the SAR image-DEM coregistration step.

The paper is organized as follows: Section 2 presents the experimental analysis used to evaluate the robustness of the scattering-based algorithms; a comparison with the original filters is provided for completeness. Section 3 draws some relevant conclusions and comments.

2. SENSITIVITY ANALYSIS OF THE SCATTERING-BASED DESPECKLING ALGORITHMS

The robustness of the scattering-based algorithms is evaluated by means of simulation tools. In particular, the SARAS simulator [6] is used to compute the SAR image relevant to a fractal DEM with fractal dimension $D = 2.2$, topothesy $T = 10^{-4}$ m, relative dielectric constant $\varepsilon_r = 4$ and electrical conductivity $\sigma = 10^{-2}$ S/m. All the surface parameters and the DEM are assumed to be known in the scattering-based filters.

In order to assess the robustness of the scattering-based filters against the scattering behavior of the surface, the algorithms are applied to SAR images of the fractal scene previously described simulated assuming different scattering models. In particular, besides the SPM model (Fig. 1) used in the theoretical derivation of the filters [2], [3], the $\cos\vartheta$ (Fig. 2) and the $\cos^4\vartheta$ (Fig. 3) scattering models are used for simulation purposes. Single-look SAR images are shown in Fig. 1-3(a). 512-look images (Fig. 1-3b) are used as reference for qualitative and quantitative performance evaluation. Despeckled images using SB-PPB are shown in Fig. 1-3(c); PPB in Fig. 1-3(d); SB-SARBM3D in Fig. 1-3(e); SARBM3D in Fig. 1-3(f). The signal-to-noise (SNR) ratio and the coefficient of variation C_x are used as synthetic performance measures (see Table I). Coherently with the theoretical framework derived in [2] and [3], the most accurate results are obtained if the scattering behavior of the surface is correctly described by the SPM model (Fig. 1). If this is not the case, the more isotropic the scattering, the worse the results. For the considered scattering models, the worst results in terms of SNR are obtained with the $\cos \vartheta$ scattering model, while the $\cos^4 \vartheta$ model provides intermediate results (see Table I). The poor performance in the $\cos \vartheta$ case in terms of SNR can be partially due to the inadequacy of the Lambertian model to describe the scattering mechanisms at microwaves frequencies.

However, a good texture preservation is provided by the scattering-based algorithms whatever the scattering model, as witnessed by the coefficient of variation in Table I. SB-SARBM3D exhibits a more significant sensitivity against the scattering behavior of the surface with respect to SB-PPB.

To provide a comprehensive understanding of the analysis, the sensitivity of the algorithms is evaluated for different DEM resolutions. For any DEM resolution, coregistration errors between the DEM and the SAR image are simulated via an increasing displacement of the local incidence angle map with respect to the SAR image in Fig. 1(a).

The SNR shown in Figs. 5 indicates that the lower the DEM resolution, the stronger the robustness of SB-PPB against coregistration displacements. Consequently, a particular attention to the coregistration step should be paid in presence of a high-resolution DEMs. In this case, a significant performance degradation can be experienced if the coregistration step is not accurate. This is due to the significant spatial high-frequency content of the a priori scattering information in the case of high-resolution DEMs. On the contrary, the more homogeneous scattering information estimated from low-resolution DEMs causes a higher robustness of the performance even in presence of gross coregistration errors. However, with high-resolution DEMs, better performance is provided at the cost of a precise coregistration step.

3. CONCLUSIONS

In this paper, a sensitivity analysis of the recent scattering-based despeckling algorithms, namely SB-PPB and SB-SARBM3D is experimentally conducted. In particular, the sensitivity analysis evaluates the influence of:

- the scattering behavior of the surface;
- errors in the SAR image-DEM coregistration step.

Concerning the first issue, different scattering models have been used to simulate the scattering behavior of the surface. Best performance is ensured wherein the scattering behavior of the surface is well-described by the SPM model used in the theoretical derivation of the scattering-based algorithms; in more general terms, the more accurate the SPM model, the better the performance of the filter.

The DEM resolution plays a key role in the robustness of SB-PPB and SB-SARBM3D against coregistration mismatches between the SAR image and the DEM. Thus, a high-resolution DEM, even if providing a richly detailed a priori scattering information, causes a significant performance drop in presence of coregistration errors, unless the topography is gentle enough. On the contrary, low-resolution DEMs allow a higher robustness of the filter performance against errors in the coregistration step, thanks to the smoother a priori information.

4. REFERENCES

[1] G. Di Martino, A. Di Simone, A. Iodice, D. Riccio and G. Ruello, "Non-Local Means SAR Despeckling Based on Scattering," in *IEEE Int. Geosci. Remote Sens. Symp.*, pp. 3172-3174, Milan, Jul. 2015.

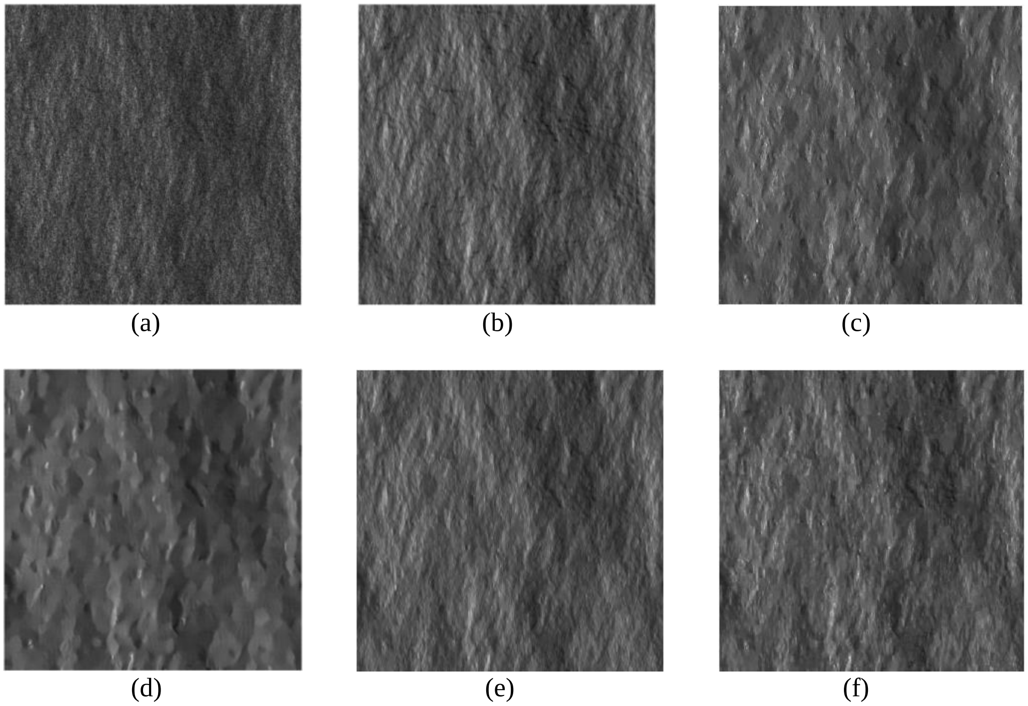
[2] G. Di Martino, A. Di Simone, A. Iodice, and D. Riccio, “Scattering-Based Nonlocal Means SAR Despeckling,” *IEEE Trans. Geosci. Remote Sens.*, vol. 54, no. 6, pp. 3574-3588, Jun. 2016.

[3] G. Di Martino, A. Di Simone, A. Iodice, G. Poggi, D. Riccio, L. Verdoliva, “Scattering-Based SARBM3D,” *IEEE J. Sel. Topics Appl. Earth Observ. Remote Sens.*, vol. 9, no. 6, pp. 2131-2144, Jun. 2016.

[4] C.-A. Deledalle, L. Denis and F. Tupin, "Iterative Weighted Maximum Likelihood Denoising With Probabilistic Patch-Based Weights," *IEEE Trans. Image Process.*, vol. 18, no. 12, pp. 2661-2672, Dec. 2009.

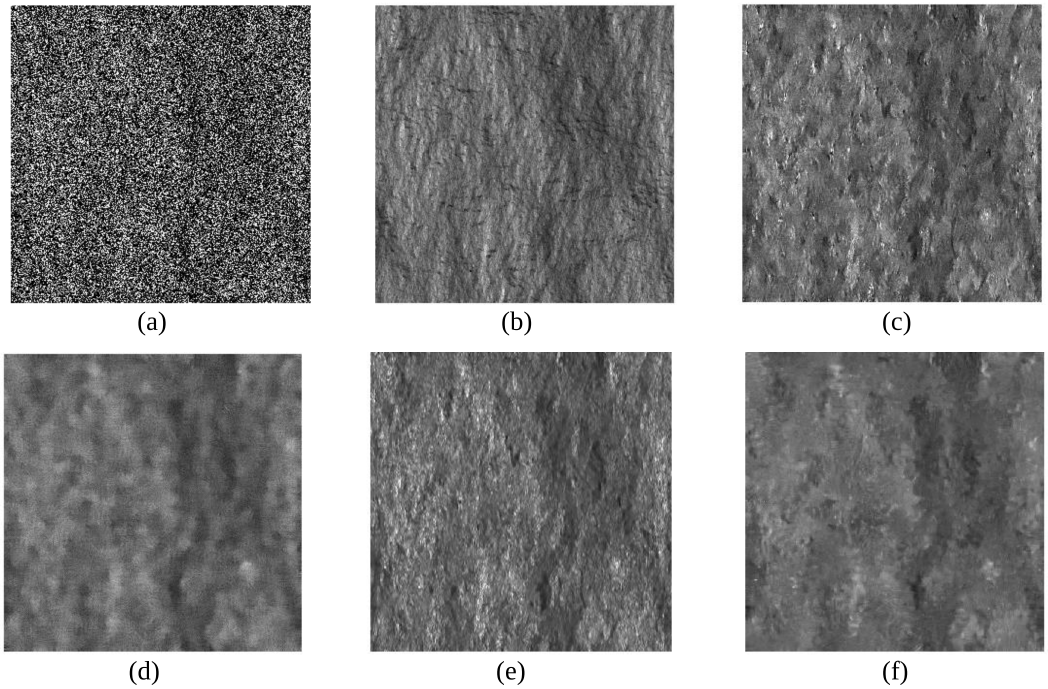
[5] S. Parrilli, M. Poderico, C. V. Angelino and L. Verdoliva, "A Nonlocal SAR Image Denoising Algorithm Based on LLMMSE Wavelet Shrinkage," *IEEE Trans. Geosci. Remote Sens.*, vol. 50, no. 2, pp. 606-616, Feb. 2012.

[6] G. Franceschetti, M. Migliaccio, D. Riccio and G. Schirinzi, "SARAS: a synthetic aperture radar (SAR) raw signal simulator," *IEEE Trans. Geosci. Remote Sens.*, vol. 30, no. 1, pp. 110-123, Jan. 1992.


(a) (b) (c)

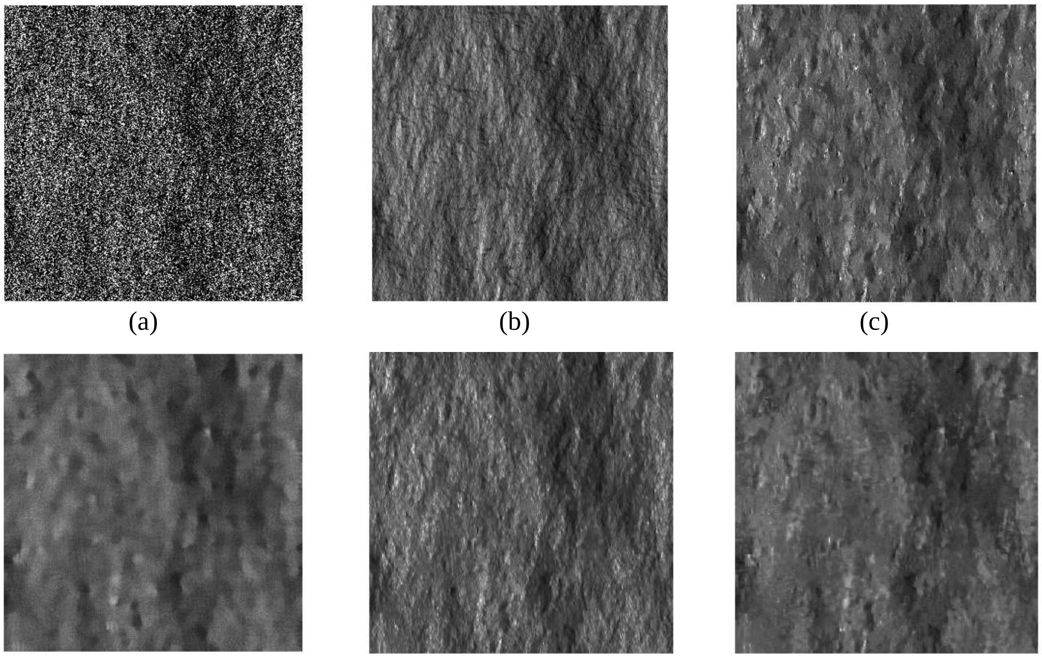
(d) (e) (f)

Fig. 1: (a) 512x512 single-look SAR image relevant to a DEM with fractal parameters $D = 2.2$, $T = 10^{-4}$ m and electromagnetic parameters $\varepsilon_r = 4$ and $\sigma = 10^{-2}$ S/m; (b) 512-look image; (c) SB-PPB; (d) PPB with four iterations; (e) SB-SARBM3D; (f) SARBM3D.


(a) (b) (c)

(d) (e) (f)

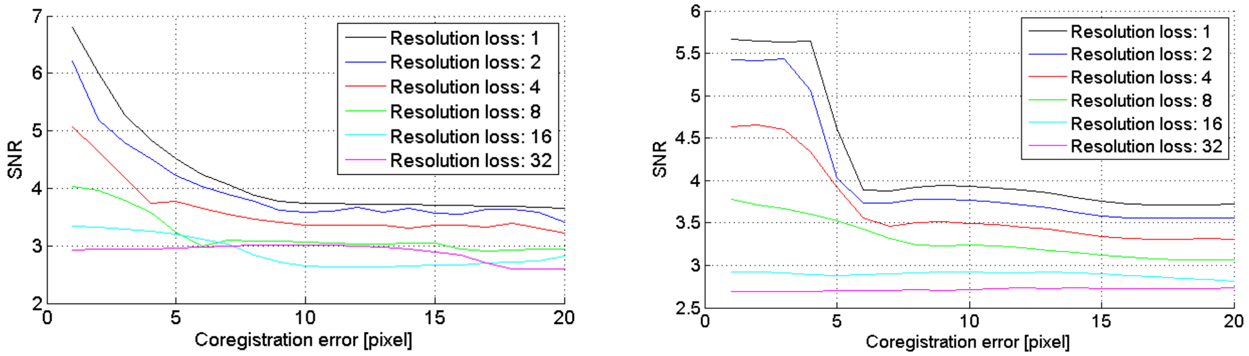
Fig. 2: Simulated and despeckled SAR images assuming the $\cos\vartheta$ scattering model. (a) Noisy; (b) reference SAR image; (c) SB-PPB; (d) PPB with four iterations; (e) SB-SARBM3D; (f) SARBM3D.



(a) (b) (c)

(d) (e) (f)

Fig. 3: Simulated and despeckled SAR images assuming the $\cos^4\vartheta$ scattering model. (a) Noisy; (b) reference SAR image; (c) SB-PPB; (d) PPB with four iterations; (e) SB-SARBM3D; (f) SARBM3D.



(a) (b)

Fig. 4: Sensitivity of (a) SB-SARBM3D and (b) SB-PPB against coregistration errors (in pixels) between the local incidence angle map and the SAR image for different DEM resolutions.

TABLE I
PERFORMANCE PARAMETERS FOR VARIOUS SCATTERING MODELS

	SPM		$\cos\vartheta$		$\cos^4\vartheta$	
	SNR	C_x	SNR	C_x	SNR	C_x
Reference	∞	0.67	∞	0.15	∞	0.26
PPB	3.47	0.51	0.68	0.12	1.98	0.18
SARBM3D	4.84	0.57	1.31	0.11	2.62	0.19
SB-PPB	5.67	0.57	-0.084	0.18	2.90	0.25
SB-SARBM3D	6.80	0.55	0.93	0.17	4.02	0.25