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Speckle Reduction in Polarimetric Synthetic Aperture Radar Images on Multicores

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Abstract

An algorithm for speckle noise reduction in color images is proposed. The method is applied to polarimetric synthetic aperture radar (PolSAR) images. PolSAR images are corrupted by speckle noise that complicates the target recognition and classification. Due to the computational cost of the filtering process and the large size of the images, a parallel implementation of the method is developed on multicore platforms. Experiments in color images are carried out to demonstrate the efficiency of the algorithm using objective quality measures. The efficiency of the algorithm is also proved in real PolSAR images. The results show the computational efficiency of the parallel implementation on multicore platforms, obtaining speedup values in the range 8.85 to 10.89 when the 12 cores of the multicore platform are used.

Keywords: parallel computing, multicore, noise reduction, speckle noise, speckle reduction, polarimetric synthetic aperture radar.

1 Introduction

Polarimetric synthetic aperture radar (PolSAR) images are hardly contaminated with speckle noise. This distortion makes difficult the interpretation of data and the recognition and classification of targets. For this reason, the elimination of speckle noise is essential in PolSAR images [1,2]. In this work we propose a method for the elimination of speckle noise in color images and we apply it to PolSAR images. The method is based on the algorithm introduced in [3]. In [3] a three-stage hybrid algorithm is proposed to eliminate speckle noise in ultrasound images. In [4] a parallel method based on the algorithm introduced in [3] was presented in order to reduce the computation time. The method presented in [3] was designed for grayscale images. In this work we propose an extension of the hybrid algorithm proposed in [3] to color images and we use it to filter PolSAR images. Due to the computational cost of the algorithm and the large size of the PolSAR images, we developed a parallel implementation of the proposed method on multicore platforms using OpenMP. To analyze the filtering efficiency of the proposed method we carry out experiments in digital color images. The results obtained using the objective measures of quality MSE, IEF and PSNR show the efficiency of the proposed method. The efficiency of the method in PolSAR images is also demonstrated. The CNR measure is used for this purpose. A study of the speedup of the parallel implementation on a multicore architecture is carried out obtaining speedup values in the range 8.85 to 10.89 when the 12 cores of the multicore platform are used.

2 Methods

The proposed hybrid method consists of three stages:

- Stage 1: Guided filter with color guidance image.
- Stage 2: Speckle reducing bilateral filter.
- Stage 3: Rotationally invariant filter of the non-local means.

In the first stage of the method we use the guided filter (GF) for color images proposed in [5]. At the second stage we extend the speckle reducing bilateral filter (SRBF) proposed in [3] to color images. For this purpose we apply the SRBF filter proposed in [3] to each channel of the color image. At the third stage we extend the rotation invariant bilateral nonlocal means filter (RIBNLM) introduced in [6] to color images by applying that method to each channel of the color image.

In order to describe the parallel implementation of the algorithm, the image domain Ω is divided into P subdomains $\{\Omega_i, i=1,...,P\}$, where P is the number of computing elements. Figure 1 presents an example of the decomposition used in the experiments. In this example, the image is distributed into four subdomains.

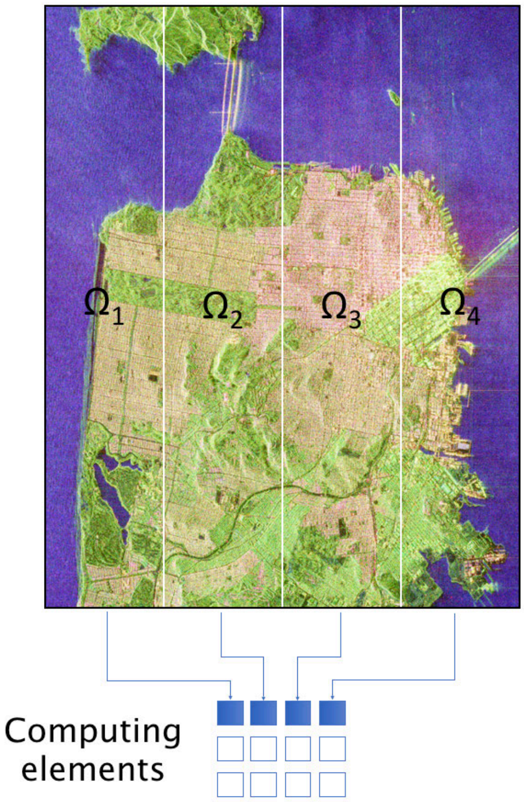


Figure 1: Image decomposition in four subdomains. San Francisco PolSAR image (size 2912 ×2304 pixels).

3 Results

We have developed a parallel implementation of the method on a multicore platform using the Open Multi-Processing (OpenMP) [7]. Both the serial code and parallel implementations were coded in Fortran. The GNU Fortran (GCC) 6.4.0 was employed. The experiments were carried on a multi-core Intel Xeon CPU X5660 (12 cores), 2,8 GHz, with 48 GB RAM, under the operative system CentOS Linux version 5.6. Different digital color images obtained from public database [8] were used in the experiments (see Figure 2). These images were contaminated with different intensities of speckle noise with variance $\sigma = 0.2$, $\sigma = 0.4$, $\sigma = 0.6$ and $\sigma = 0.8$. Moreover, the method was tested on Real PolSAR images from [9] (see Figure 1). The combination of the input parameters in the three stages of the hybrid method was found experimentally as the best option through an exhaustive search with different images and noise conditions. To measure the parallel performance, the speedup S_P is computed as $S_P = T_{seq} / T_P$ where T_{seq} is the computational time of the sequential method and T_P is the computational time of the parallel method.

Tables 1 and 2 show the denoising performance in terms of the mean-square error (MSE), the image enhancement factor (IEF) and the peak signal-to-noise ratio (PSNR) for the parrots image corrupted with different levels of speckle noise. The low values of MSE and high values of PSNR and IEF at all noise levels, confirm the good denoising performance of the proposed hybrid algorithm. Similar conclusions were obtained for all the images tested.
For the real PolSAR images we compute the contrast-to-noise ratio (CNR) measure. The CNR obtained for the San Francisco PolSAR image (Figure 1) was 18.26.

Figure 2: Parrots image from [8] (size 512 × 768 pixels).

	Noise $\sigma = 0.2$			Noise $\sigma = 0.4$		
	MSE	PSNR	IEF	MSE	PSNR	IEF
Noisy	2208.82	14.68	1.00	4127.38	11.97	1.00
Proposed method	213.81	24.83	10.33	397.03	22.14	10.39

Table 1: Quality measures MSE, PSNR and IEF. Parrots image contaminated by speckle noise $\sigma = 0.2$ and $\sigma = 0.4$.

	Noise σ = 0.6			Noise σ = 0.8		
	MSE	PSNR	IEF	MSE	PSNR	IEF
Noisy	5387.38	10.81	1.00	6252.48	10.17	1.00
Proposed method	493.86	21.19	10.90	606.69	20.30	10.30

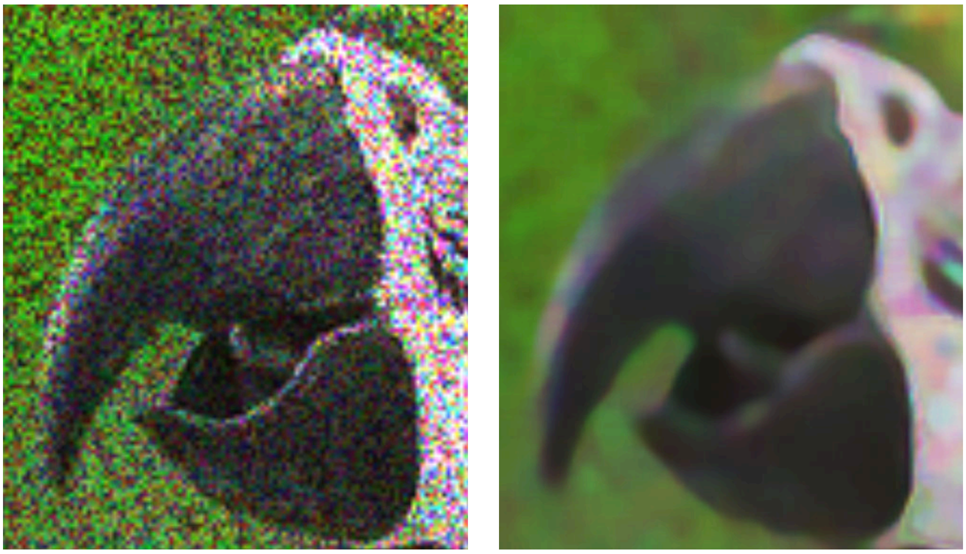
Table 2: Quality measures MSE, PSNR and IEF. Parrots image contaminated by speckle noise σ = 0.6 and σ = 0.8.

Table 3 presents the computational time, speed-up and efficiency achieved for the parrots image contaminated with different levels of speckle noise (variance σ = 0.2, σ = 0.4, σ = 0.6, and σ = 0.8) and for the San Francisco PolSAR image. It can be observed that the intensity of noise does not affect the computational time. This fact is due to the characteristics of the filters involved in the hybrid method. Results show that the parallel method achieves speedups in the range 8.85 to 10.89 when the 12 cores of the multicore platform are used.

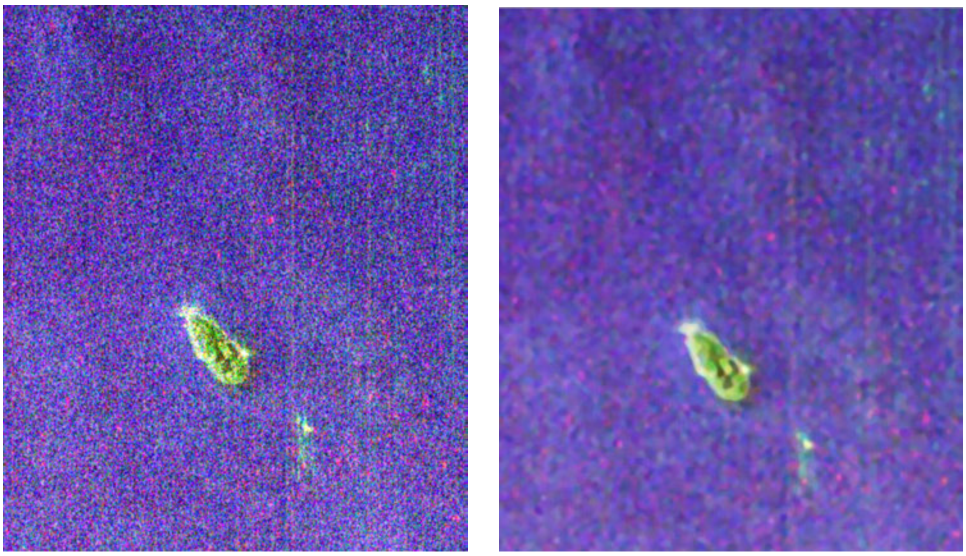
Image	Sequential time (seconds)	Parallel Time (seconds)	Speedup	Efficiency %
Parrots corrupted with σ= 0.2	8.20	0.92	8.85	73.75
Parrots corrupted with σ= 0.4	8.15	0.89	9.15	76.25
Parrots corrupted with σ= 0.6	8.23	0.91	9.04	75.33
Parrots corrupted with σ= 0.8	8.19	0.92	8.91	74.25
San Francisco PolSAR	141.21	12.96	10.89	90.75

Table 3: Computacional time in seconds, speed-up and efficiency.

In terms of visual appearance, the filtered images presented in Figure 3, show that the proposed method properly retains the image details and effectively reduces the speckle noise.



(a) (b)



(c) (d)

Figure 3: Filter outputs for visual inspection. (a) Detail of parrots image corrupted with $\sigma = 0.2$, (b) Filtered image, (c) Detail of Alcatraz island in PolSAR image, (d) Filtered image.

4 Conclusions and Contributions

A parallel algorithm to remove speckle noise in color images has been introduced. This method combines, in three steps, the color guided filter, the extension of the speckle reducing bilateral filter to color images and the rotation invariant bilateral nonlocal means filter extended to color images. The algorithm has been implemented on a multicore platform using OpenMP and Fortran. The parallel method has been used to reduce the speckle noise in color images corrupted with different levels of speckle noise and on real PolSAR images. The experimental results show that the proposed filter obtains outstanding values for the usual objective quality measures MSE, PSNR, IEF and CNR. The parallel algorithm introduced demonstrated a significant speed-up in the range 8.85 to 10.89 when the 12 cores of the multicore machine are employed. In future works, we will implement the method on clusters of multicores using hybrid MPI-OpenMP programming and on GPUs using CUDA.

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