SAR DESPECKLING GUIDED BY AN OPTICAL IMAGE

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ABSTRACT

We address the problem of SAR despeckling by resorting to nonlocal filtering guided by an optical image. In fact, given the increasing availability of remote-sensing optical images, it makes perfect sense trying to use them to improve the performance of despeckling. Our technique exploits the optical image to reliably estimate the statistical similarity among pixels, which is used to evaluate the weights of nonlocal filtering. Optical data are not used to estimate SAR values, but only to guide the overall process. In addition, they are discarded altogether in regions where SAR and optical images present different local geometries, identified by a preliminary classification step, avoiding thus any additional distortion. Experimental results show the proposed approach to provide images of better quality than state-of-the-art conventional filters.

Index Terms— SAR despeckling, nonlocal filtering, bilateral filter, SAR-optical fusion.

1. INTRODUCTION

SAR images are more and more often processed by computer algorithms, in which case a preliminary despeckling step is necessary to suppress, or at least reduce, the strong speckle component, modeled often as a multiplicative noise, which would otherwise impair all processing products. With modern fleets of SAR sensors, delivering a huge number of images with very-high spatial resolution, the need for effective despeckling becomes only more pressing. On the other hand, this wealth of information allows one to develop and use more advanced despeckling tools. For example, given a multi-temporal stack of co-registered SAR images, one can take advantage of time dependencies by carrying out a temporal multilooking, or using some more sophisticated filters, like [1], which reduce speckle with no loss of spatial resolution. Following the same rationale, the obvious next step is to use optical data to improve despeckling. Indeed, in parallel with radar sensors, also optical sensors are being deployed at an unprecedented rate, providing valuable remote-sensing data that could be taken into account through a careful fusion of information. In particular, optical images are typically collected over a multiplicity of spectral bands and are little affected by noise, therefore can represent a valuable guide. Based on these considerations, we propose here a new SAR despeckling approach in which the filtering process is aided by a co-registered optical image of the same scene.

The idea of using a pilot image to drive the filtering process is certainly not new. Several state-of-the-art denoising and despeckling techniques [2, 3, 4] rely on a pilot image, typically extracted from the very same image to be filtered, to estimate important image statistics, select predictors, or carry out other tasks otherwise unfeasible on the noisy original. Recently, this idea has led to the definition of the guided filters [5], in which the presence of an external pilot image is exploited to perform a fast and effective image denoising.

Our aim is to extend this concept to the SAR/optical remote sensing case, retaining the precious peculiar information of the SAR image, but with the higher accuracy associated with the optical image. This extension, however, is not straightforward, given the very different imaging mechanisms of radar and optical images which impacts on their geometrical and statistical properties. We therefore propose specific solutions including a suitable classification of the image and the development of a specific guided nonlocal filter. We will describe the proposed solutions in next Section and present some experimental results in Section 3.

2. PROPOSED METHOD

In Fig.1 we show a 512×512-pixel section of a single-look COSMO-SkyMed SAR image, together with a Worldview multispectral image of the same area, co-registered with it. There is a striking gap in image quality: the optical image is much cleaner, showing readily information about the land cover that in the SAR image is hidden by speckle and can be partially recovered only thanks to user expertise and a priori knowledge. Needless to say, a computer algorithm working on such a noisy input is bounded to provide very disappointing results. Therefore, given the optical image, it makes full sense trying to use it as a side information to improve SAR despeckling. However, we should not inject optical data into the SAR image, lest we lose the precious peculiar information associated with the radar imaging.

To gain better insight into this point, Fig.1 shows also a despeckled version of the input image obtained by jointly fil-

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Fig. 1. A single-look SAR image, a co-registered optical image, and the SAR image despeckled based on a multitemporal data.

tering [1] 11 co-registered SAR images of the same scene. This is a pretty good approximation (ENL≃10) of the desired despeckled image, showing much less speckle than the original with no loss in spatial resolution. Note that this image exhibits important structural differences w.r.t. the optical image, especially for what concerns man-made objects and (not present in this section) regions characterized by a significant orography, differences which should be carefully preserved.

Therefore, we want to exploit, as far as possible, the reliable information coming from the pilot optical image, while processing exclusively the original SAR data. The use of a pilot image has been long pursued in image denoising. However, only in the context of nonlocal filtering [6] it expresses its full potential. As the name suggests, in fact, nonlocal methods estimate the true value of a pixel based not on the closest pixels but on those that are more statistically homogeneous with it. So, for example, to estimate the true value of a near-edge pixel, only other near-edge pixels are used and not pixels drawn form a flat area. Nonlocal methods have been successfully used on different products of SAR imagery [7] and the major issue is the identification of the best predictor pixels for the current target. In BM3D [2] and its SAR oriented version, SAR-BM3D [3], for example, this is achieved by resorting to a pilot image obtained by a pre-filtering of the image itself. We underline explicitly that the pilot is used only to find the predictor locations, while all estimates are based on values observed in the original image. Of course, the more reliable the pilot, the better the predictor selection, which motivates our interest for the co-registered optical image.

Fig.2 shows a block diagram of the proposed method. The single-look SAR image is first used to drive the co-registration of the optical image of the same scene. The latter is then used to guide the SAR despeckling. In parallel, the SAR image is also despeckled by means of a technique operating exclusively in the SAR domain. The two despeckled versions of the image are eventually combined with suitable weights computed on the SAR image itself.

To implement the optical-guided filtering, we resort to the

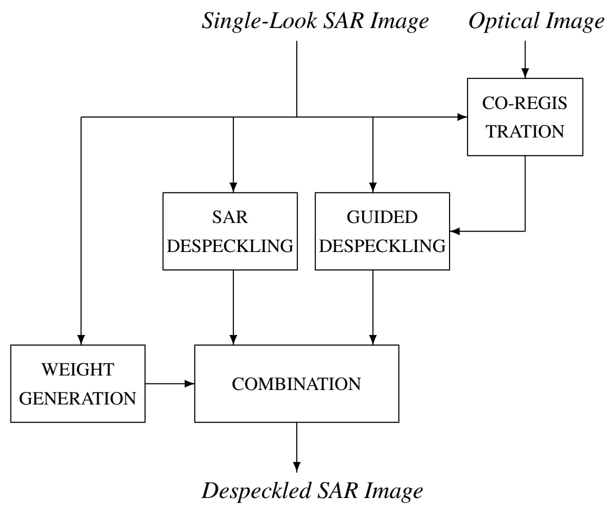

Fig. 2. Block diagram of the proposed method.

bilateral filter [8], already used with good results for SAR despeckling [9], The target value $x(t)$ is estimated as a linear combination of values $y(s)$ observed in a surrounding window $\Omega(t)$. In the original filter, the weights depend not only on the spatial distance $\|t-s\|$ between target and predictor, but also on their range distance $\|y(t)-y(s)\|$, taken as a rough estimate of their similarity.

Here, we modify the original filter to take into account both the peculiarities of SAR data and the availability of an optical pilot. More specifically, each pixel is still estimated as a weighted sum of neighbors

$$\widehat{x}(t) = \sum_{s\in\Omega(t)} w(s,t)\, y(s) \tag{1}$$

but the weights are computed as

$$\begin{aligned} w(s,t) = \quad & C \exp\left\{-\lambda_S \|t-s\|^2 - \lambda_{R_1} \|z(t)-z(s)\|^2 \right. \\ & \left. -\lambda_{R_2} \log_2 \left[y(t)/y(s) - y(s)/y(t)\right]\right\} \end{aligned} \tag{2}$$

where λ_S, λ_{R_1} and λ_{R_2} are suitable decay parameters in the spatial and range domains, and C is a normalizing constant. Note the inclusion of a term depending on the optical data $z(\cdot)$ and the use of the SAR-specific distance, proposed in [10], for the SAR data $y(\cdot)$. SAR-domain despeckling is carried out by the SAR-BM3D algorithm [3], a nonlocal technique especially effective [11] on image details.

Structural differences between SAR and optical sources are taken into account by suitable weights used in the combination. In man-made areas, optical-guided despeckling should be discarded, because it follows a wrong geometry. Conversely, in natural areas, SAR-domain despeckling can be mostly neglected, as it provides only a limited suppression of speckle. The weights are obtained by averaging the local coefficients of variation computed on square windows of different sizes, from 3×3 to 27×27, and then passing the output through a sigmoid non-linearity.

3. EXPERIMENTAL RESULTS

In this section we show some experimental results obtained on a single-look CosmoSkyMed SAR image of a region near Caserta (I) using as guide a GeoEye-1 optical image of the same area. In Fig.3 and Fig.4 we show, for two clips of the image, the intermediate products of the filtering process, namely the output of SAR-domain and optical-guided despeckling, and the combination map, together with final result. In both cases the filtered images have a very good appearance with speckle reduced in homogeneous areas, and fine detailed preserved thanks to the classification-based strategy.

In Fig.5 we show sample results for a 512×192-pixel close-up of the clip of Fig.4. Besides the original single-look image, we show the output of plain multilooking (L=25), enhanced Lee filtering [12] with 5×5 window, PPB [10] with 25 iterations, SAR-BM3D and the proposed method. With the Lee filter, a clear loss of spatial resolution is observed, with a limited suppression of speckle. Details are better preserved with the nonlocal PPB and SAR-BM3D. The former guarantees a better speckle suppression in homogeneous areas, though with some artifacts, while the latter exhibits a better performance on man-made areas. Finally, the proposed method exerts a powerful despeckling in homogeneous areas, fully respectful of the original data and with no obvious artifacts, while preserving details accurately in the man-made regions. Of course, the comparison is not fair, as the last method takes advantage of important side information. However, such information is often available and should be used to achieve results that would be out of reach otherwise.

Obviously, to fully understand the potential of this approach a more thorough analysis should be conducted, both for the fusion technique and for the performance evaluation. In our future work we will certainly follow this path in order to better exploit the information conveyed by the corresponding optical image.

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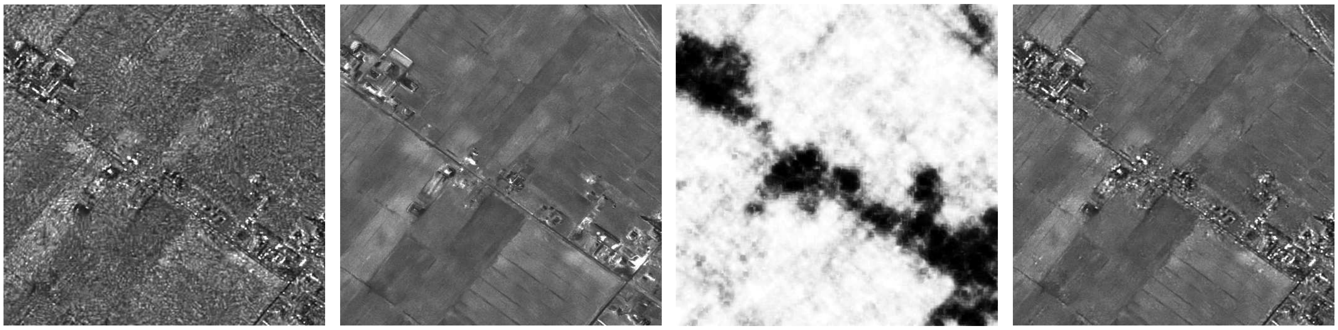

Fig. 3. Output of SAR-domain and optical-guided despeckling, weight map, and final result obtained through combination.

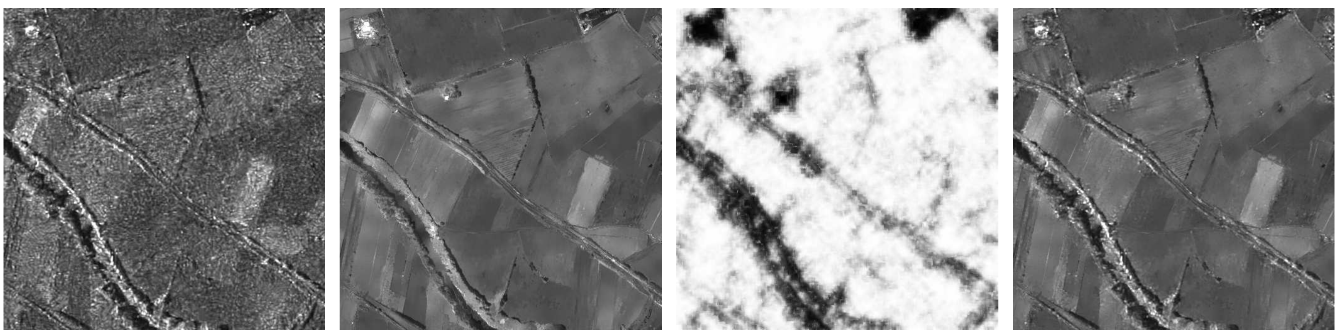

Fig. 4. Output of SAR-domain and optical-guided despeckling, weight map, and final result obtained through combination.

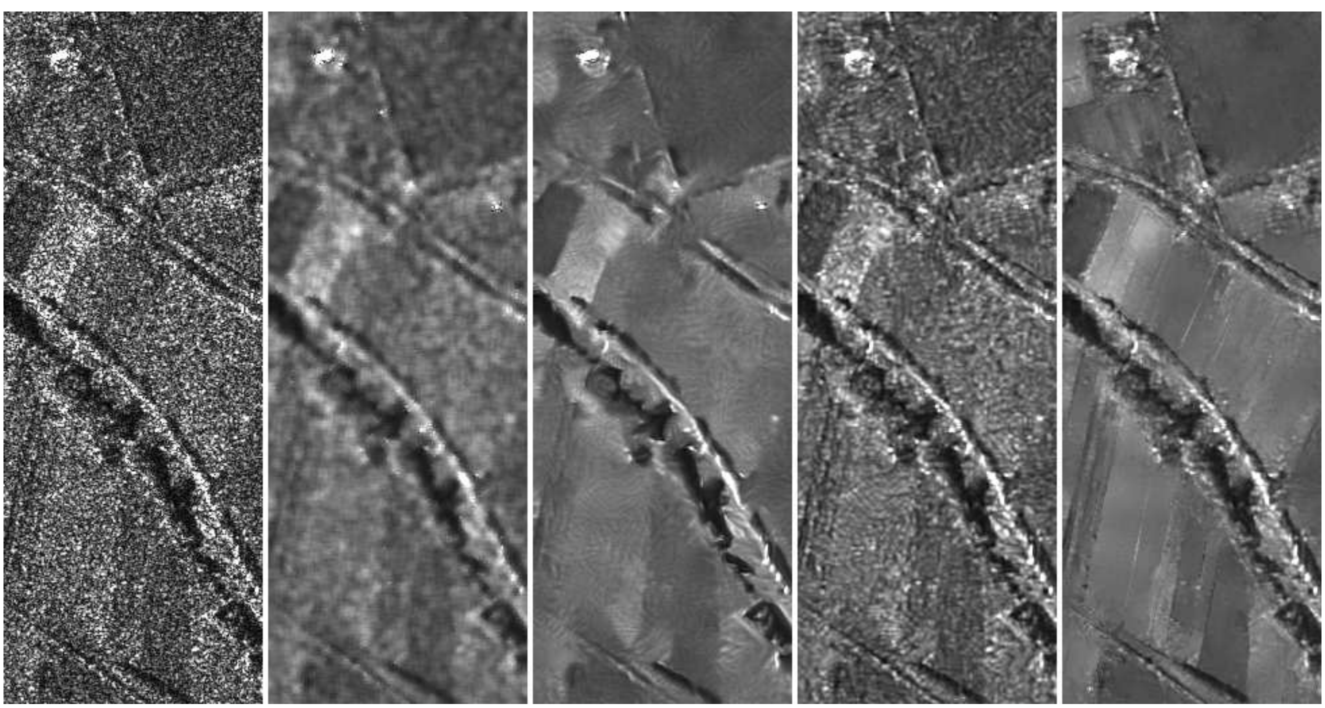

Fig. 5. Close-up of despeckling results: original, Enhanced Lee, PPB, SAR-BM3D, proposed.