Riesz transform for synthetic aperture radar images analysis: An application for oil spill detection

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Keywords: SAR image; Oil spill; Speckle noise; Riesz transform; Riesz wavelets.

1.1 Introduction

Synthetic aperture radar (SAR) has the capability to offer significant comprehensive data regarding the location and dimensions of a specific oil spill during moderate wind conditions (4–12 m/s), regardless of day or night (Brekke & Solberg, 2005; Vasconcelos et al., 2020). However, these images are characterized by multiplicative noise called speckle (Kumar et al., 2018, 2020; Tounsi et al., 2023). This noise is due to the high coherence of the radar waves; the backscattered waves by the rough earth surface self-interfere, and these random self-interferences appear as dark and bright grains in the recorded data.

In this work, Riesz transform-based methods are developed to reduce the speckle noise on one hand and improve the quality of oil spill detection on the other.
The Riesz transform has a long tradition in mathematics and has been studied extensively in the context of Calderón-Sygmund's theory of singular integral operators. Its introduction to signal processing is more recent. It is defined as the multidimensional extension of the Hilbert transform for image analysis. It satisfies a steerable property with respect to rotation and is thus suitable for image analysis. This tool has shown its performance for fringe pattern analysis in optical metrology (Tounsi et al., 2020).
Regarding speckle denoising, the proposed method concerns speckle noise, which is considered as undesired information and should be removed from the SAR images after their analysis. This method consists of combining the Riesz transform and wavelet thresholding technique. The effectiveness of the proposed method is assessed using three important criteria: peak-to-signal-noise ratio (PSNR), the quality index Q, and the edge preservation index. The obtained metric values demonstrate that this technique can enhance both PSNR and Q compared to other well-known methods such as Frost filter, Lee filter, and Wiener filter. These metrics indicate not only enhanced visual clarity but also greater analytical precision in subsequent processing stages.
The second method consists of using the Riesz transform components of the input SAR image for oil spill characterization. The procedure begins by computing the first-order Riesz components and then extracting the amplitude map, phase map, and the orientation map of the input image. These extracted features are important to improve the quality of the detected oil spill from SAR image.
The entire workflow, from reducing noise to extracting key features, is streamlined within our user-friendly MATLAB-based Riesz Toolbox. This tool is crafted for high efficiency and ease of use, ensuring that images are processed quickly. Its swift performance makes it an ideal choice for operational settings where time is of the essence.

1.2 Methodology and some finding

The high-order Riesz transform kernel is defined as mathematically as:

$$R^n(x,y) = \frac{n i^n (x+iy)^n}{2\pi\left(x^2+y^2\right)^{n+3/2}},$$

where (x, y) represents the spatial coordinate position, n denotes the order of the Riesz operator, and i is the square root of -1, the expressions for the first-order two-dimensional (2D)-Riesz kernels along the x and y directions are provided as follows:

$$R_x = \frac{-x}{2\pi(x^2+y^2)^{3/2}}, R_y = \frac{-y}{2\pi(x^2+y^2)^{3/2}}$$

These expressions represent the first-order Riesz kernels along the x and y directions, illustrating the spatial variation in the corresponding Riesz wavelet components. These two filters R_x and R_y are characterized by their frequency responses as shown in Fig. 1:

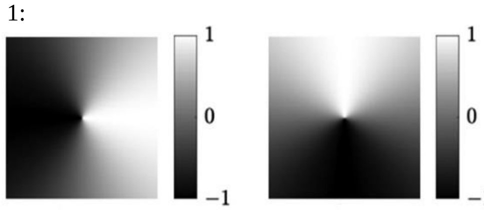

Fig.1: Frequency responses of first order Riesz transform

The proposed speckle noise reduction method (Riesz thresholding wavelets) is primarily based on the analysis of Riesz wavelets from the speckle fringe configuration and the thresholding technique of standard coefficients. Prior to performing the Riesz wavelet decomposition on the input image, the acquired Riesz wavelet coefficients undergo a thresholding process. We specifically choose soft thresholding for its visually smoother impact on the image compared to the harsher effects of hard thresholding.
Subsequently, the inverse Riesz wavelet transform is applied to reconstruct the denoised output image from the thresholded coefficients.
The denoising method proposed relies on two parameters: the order of the Riesz transform and the scale of decomposition.
These metrics are computed by varying the speckle noise variance and the following table summarizes the obtained values.

Table 1: Performance of the proposed method

Speckle variance	PSNR	SSIM	EPI
10	38,49	0,79	0,96
20	38,61	0,74	0,95
30	30,04	0,66	0,93
40	30,61	0,59	0,92
50	29,50	0,52	0,91
60	28,73	0,48	0,90
70	26,14	0,44	0,88
80	20,37	0,40	0,87
90	18,91	0,36	0,86
100	16,12	0,33	0,85

The metrics values demonstrate the high performance of the proposed method for speckle reducing from SAR image. The different values of speckle variance represent the roughness of the earth surface. The obtained results suggest that the proposed method for speckle noise filtering is effective and could be established as a powerful tool for filtering speckle noise in radar imaging.

References

Brekke, C., & Solberg, A. H. S. (2005). Feature extraction for oil spill detection based on SAR images. *Lecture Notes in Computer Science*, *3540*, 75–84. https://doi.org/10.1007/11499145_9/COVER

Kumar, M., Mendoza-Santoyo, F., Nassim, A., & Tounsi, Y. (2018). Speckle noise reduction in digital speckle pattern interferometric fringes by nonlocal means and its related adaptive kernel-based methods. Applied Optics, Vol. 57, Issue 27, Pp. 7681-7690, 57(27), 7681–7690. https://doi.org/10.1364/AO.57.007681

Kumar, M., Tounsi, Y., Kaur, K., Nassim, A., Mandoza-Santoyo, F., & Matoba, O. (2020). Speckle denoising techniques in imaging systems. Journal of Optics, 22(6), 063001. https://doi.org/10.1088/2040-8986/AB8B7F

Tounsi, Y., Kumar, M., Kaur, K., Santoyo, F. M., Matoba, O., & Nassim, A. (2023). Speckle-noise filtering based on non-local mean sparse principal component analysis method. Optics and Lasers in Engineering, 164, 107507. https://doi.org/10.1016/J.OPTLASENG.2023.107507

Tounsi, Y., Kumar, M., Siari, A., Santoyo, F. M., Matoba, O., & Nassim, A. (2020). Riesz transform for fringes pattern analysis: advantages and limitations. Https://Doi.Org/10.1117/12.2574757, 11551, 81–90. https://doi.org/10.1117/12.2574757

Vasconcelos, R. N., Lima, A. T. C., Lentini, C. A. D., Miranda, G. V., Mendonça, L. F., Silva, M. A., Cambuí, E. C. B., Lopes, J. M., & Porsani, M. J. (2020). Oil Spill Detection and Mapping: A 50-Year Bibliometric Analysis. Remote Sensing 2020, Vol. 12, Page 3647, 12(21), 3647. https://doi.org/10.3390/RS12213647