Universidade Federal de Pernambuco
Centro de Ciências Exatas e da Natureza

Pós-graduação em Estatística

Fusão Explicável de Evidências Estatísticas de Bordas em Imagens

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Tese de Doutorado

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Abstract

Edge detection has an essential role in post-processing of Polarimetric synthetic aperture radar (PolSAR) images. It is still a big challenge to extract all the edge features and suppress speckle noises, especially when weak/strong edges appear simultaneously inside and outside heterogeneous areas.

PolSAR images can provide more information than single-polarimetric synthetic aperture radar (SAR) images. As the prerequisite step of image processing, PolSAR edge detection is very important, which can provide important structural information for further object recognition and image interpretation of PolSAR images. However, a complex PolSAR scene usually includes both heterogenous and homogenous terrain types such as urban areas, forests, farmlands, waters, and so on.

In this thesis, we obtain the statistical properties (bias, variance) of edge point estimators in SAR/PolSAR images. In this way, we propose and evaluate new fusion and evidence selection techniques that take these properties into account.

Resumo

A detecção de bordas tem um papel essencial no pós-processamento das imagens PolSAR. A extração de todas as características das bordas e a supressão de ruídos speckle, especialmente quando bordas fracas/fortes aparecem simultaneamente dentro e fora de áreas heterogêneas, ainda é um grande desafio.

As imagens PolSAR podem fornecer mais informações do que as imagens de radar de abertura sintética (SAR) de polarimetria única. Como a etapa de pré-requisito do processamento de imagem, a detecção de bordas PolSAR é muito importante, o que pode fornecer informações estruturais importantes para reconhecimento adicional de objetos e interpretação de imagens PolSAR. No entanto, uma cena PolSAR complexa geralmente inclui tipos de terreno heterogêneos e homogêneos, como áreas urbanas, florestas, terras agrícolas, águas e assim por diante.

Nesta tese, obtemos as propriedades estatísticas (bias, variância) dos estimadores de pontos de borda em imagens SAR/PolSAR. Desta forma, propomos e avaliamos novas técnicas de fusão e seleção de evidências que levem em consideração essas propriedades.

Contents

Chapter 1

Introduction

The use of Statistical Information Theory (SIT) and Statistical Information Geometry (SIG) in image processing and analysis problems has the potential to provide several solutions to the same problem. Considering that these solutions are evidences, or estimates of the solution, this project aims to propose techniques for fusing them into a single solution potentially better than the individual evidences.

The starting point is the paper by de Borba et al. [1], in which the authors obtain several evidences of the location of edge points in images with low signal/noise relation. In this work, the estimations are treated deterministically, that is, without taking into account the variability of the estimator that produces them. These estimations go through fusion processes to obtain an edge point that summarizes the evidence.

The project proposes to create fusion techniques that take into account the quality of each evidence. In this way, evidence that is subject to high variability, or that is inconsistent with most other evidence, will have less influence on the final result.

On the one hand, the project is challenging because there are no theoretical results to assess the quality (bias, variance, etc.) of the evidence. On the other hand, when they come from an analysis based on the SIT/GIS approach, there is the possibility of advancing the frontier of knowledge since there is a powerful statistical tool (although little explored) for this purpose.

An explainable fusion of this type of evidence will be able to provide semantically valuable information on the contribution of each component to the composition of the final result. With this, end-users will be able to extract relevant information about the information content (and reliability) of each source of evidence. This knowledge will allow, for example, discarding unreliable sources, or those that, being redundant, contribute little to the quality of the product.

The work will focus on SAR/PolSAR (Synthetic Aperture Radar/Polarimetric SAR) images. These images are of great relevance in Remote Sensing [2], and present high levels of non-Gaussian and non-additive noise. This last feature makes them attractive and challenging for the development of new techniques [3].

The statistical approach to edge detection in SAR/PolSAR images has provided comparable or better results than techniques previously considered state-of-the-art. Among the edge detec-

tion results to be highlighted for SAR images (in which each pixel has a non-negative value), we mention the works of [4, 5].

1.1 Literature Review

A. Fink [6] provides the following definition: “A literature review is a systematic, explicit, and reproducible project to identify, evaluate, and interpret the existing body of recorded documents.” Literature reviews generally aim at two goals: first, they summarize existing research by identifying patterns, themes, and issues. Second, this helps identify the conceptual content of the field and can contribute to theory development.

1.1.1 Search Strategy

In order to select the most relevant articles for this study, we started by searching for papers on edge detection in SAR/PolSAR images in the most common scientific databases: Scopus, Web of Science (WoS), Science Direct (SD), Google Scholar (GS), Emerald insight (Emerald), Wiley Online Library (Wiley), Taylor & Francis Online (T&F), Springer Link (Springer), Inderscience (IS), and Informs PubsOnline (IPO).
The employed keywords were the following focused on the fields Title-Abstract-Keywords:

- ("bias correction" OR "improve estimators" OR "new estimator" OR "MLE" OR "efficient estimators" OR "maximum-likelihood estimation" OR "statistical information theory")
- AND ("boundary detection" OR "edge detection" OR "edge detection method" OR "edge detector")
- ("PolSAR images" OR "Polarimetric Synthetic Aperture Radar" OR "single-polarimetric synthetic aperture radar images" OR "SAR images")

Some works related to this topic can be seen in Table 1.1.

Author	Title	Source
	Edge detection	
Nascimento, A. D., Horta, M. M., Frery, A. C., and Cintra, R. J. (2013)[7].	Comparing edge detection methods based on stochastic entropies and distances for PolSAR imagery	IEEE journal of selected topics in applied earth observations and remote sensing
Xiang, Y., Wang, F., Wan, L., and You, H. (2017) [8]	SAR-PC: Edge detection in SAR images via an advanced phase congruency model.	Remote Sensing
Qin, X., Hu, T., Yu, W., Wang, P., Li, J., Zou, H. (2018) [9]	Edge detection of PolSAR images using statistical distance between automatically refined samples.	IEEE International Geoscience and Remote Sensing Symposium

Nascimento, A. D., Frery, A. C., Cintra, R. J. (2019) [10]	Detecting changes in fully polarimetric SAR imagery with statistical information theory.	IEEE Transactions on Geoscience and Remote Sensing
Quan, S., Xiang, D., Xiong, B., Kuang, G. (2020) [11]	Edge detection for PolSAR images integrating scattering characteristics and optimal contrast.	IEEE Geoscience and Remote Sensing Letters

Table 1.1: Papers related to edge detection

1.2 Project objectives

The objective of this thesis is to contribute to the state of the art in the fusion of evidence using a statistical approach to achieve explainable and relevant results.

The main specific objectives are:

- Obtain the statistical properties (bias, variance) of edge point estimators in SAR/PolSAR images.
- Propose and evaluate new fusion and evidence selection techniques that take these properties into account.
- Develop new features for production software, e.g. PolSARpro and SNAP.

1.3 Thesis organization

This thesis is structured in 5 chapters. In the upcoming sections of the current chapter a general overview on ...
Chapter 2 details ...
Chapter 3 explains ...

1.4 Computing platforms

This project required a vast amount of computing, preprocessing, analysis and plotting.

Chapter 2

SAR Polarimetry

2.1 Electromagnetic radiation

2.2 SAR system characteristics

2.3 Polarimetry

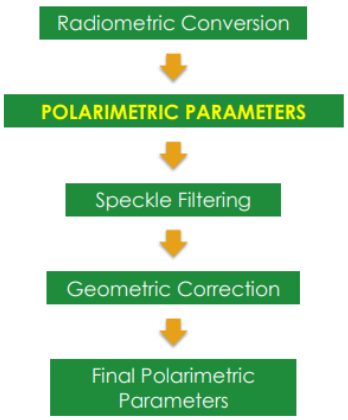

Figure 2.1 Generating Polarimetric Parameters in SNAP.

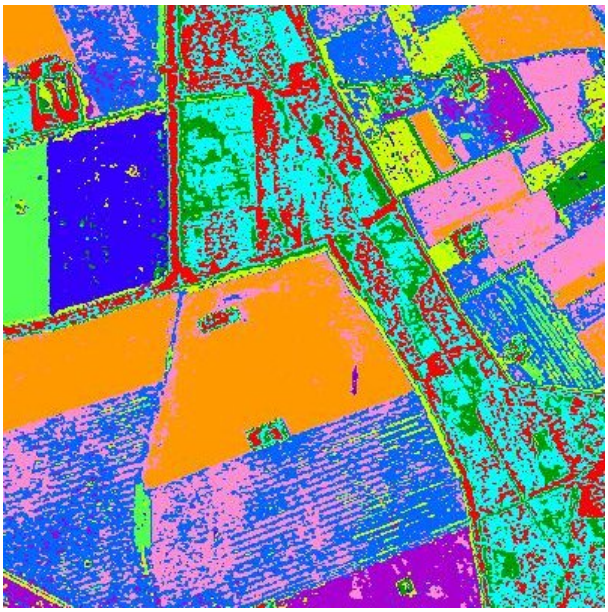

Figure 2.2 Example plot.

Example math equations

$$
\begin{aligned}
\ell(\alpha, \lambda|\boldsymbol{x}) &= \log\left[\left(\frac{\lambda^\alpha}{\Gamma(\alpha)}\right)^n \prod_{i=1}^n x_i^{\alpha-1} \times \exp\left\{-\left(\lambda \sum_{i=1}^n x_i\right)\right\}\right] \\
&= \log\left(\frac{\lambda^\alpha}{\Gamma(\alpha)}\right)^n + \log\left[\prod_{i=1}^n x_i^{\alpha-1}\right] - \lambda \sum_{i=1}^n x_i \\
&= n \log\left(\frac{\lambda^\alpha}{\Gamma(\alpha)}\right) + (\alpha - 1) \log \prod_{i=1}^n x_i - \lambda \sum_{i=1}^n x_i \\
&= n \log(\lambda^\alpha) - n \log(\Gamma(\alpha)) + (\alpha - 1) \sum_{i=1}^n \log(x_i) - \lambda \sum_{i=1}^n x_i \\
&= n\alpha \log \lambda - n \log(\Gamma(\alpha)) + (\alpha - 1) \sum_{i=1}^n \log(x_i) - \lambda \sum_{i=1}^n x_i. \qquad (2.1)
\end{aligned}
$$

Chapter 3

Methodology

As introduced in Chapter 1, several methods have also been proposed to...
This Chapter is organized as follows.

Chapter 4

Results

This chapter will discuss the results obtained during the development of this project.
As described in the previous chapter...

Chapter 5

Conclusions and future perspectives

As part of the project, we...

The work presented in this thesis..

Despite these limitations, we believe that the approach ...

In conclusion, ...

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