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Original Articles

Nonparametric edge detection in speckled imagery

Edwin Girón[a], Alejandro C. Frery[b,*], Francisco Cribari-Neto[a]

[a] Departamento de Estatística, Universidade Federal de Pernambuco, Cidade Universitária, Recife PE 50740-540, Brazil
[b] CPMAT & LCCV, Instituto de Computação, Universidade Federal de Alagoas, BR 104 Norte km 97, Maceió AL 57072-970, Brazil

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Abstract

We address the issue of edge detection in Synthetic Aperture Radar imagery. In particular, we propose nonparametric methods for edge detection, and numerically compare them to an alternative method that has been recently proposed in the literature. Our results show that some of the proposed methods display superior results and are computationally simpler than the existing method. An application to real (not simulated) data is presented and discussed.

Keywords: Edge detection; Hypothesis testing; Image analysis; Multiplicative noise; Small samples; Speckle; SAR

1. Introduction

Synthetic Aperture Radar (SAR) images are an important source of information in many applications including urban planning, environmental monitoring, crop management, oil prospection, mining exploration, wind detection, animal life detection, among others. A SAR is a coherent radar of high resolution that works on-board using a synthetic antenna of a movable platform, like an airplane or a satellite, covering extended surfaces and producing images. SAR systems employ the Doppler effect and processes the signal obtaining high spatial resolution in the direction of the platform motion [24].

During the data collection, the target remains illuminated under the antenna beam for a few moments and is observed by the radar from positions induced by its movement throughout the platform trajectory. The radar illuminates the target with a succession of pulses of a given frequency. The energy is propagated in all directions, and part of it returns to the antenna (this return is called ‘echo’). The sensor measures both the intensity and the delay between the signals sent from and received back by the antenna. The image is then formed based on the energy returned by each point on the surface.

Some of the most important features of the SAR sensor for remote sensing are:

- The active nature of the instrument makes it independent of other illumination sources, being able to gather images at any time.

* Corresponding author. Tel.: +55 82 3322 2345.
E-mail addresses: eggirona@gmail.com (E. Girón), acfrery@gmail.com, acfrery@pesquisador.cnpq.br (A.C. Frery), cribari@de.ufpe.br (F. Cribari-Neto).
URLs: http://sites.google.com/site/acfrery (A.C. Frery), http://www.de.ufpe.br/ cribari (F. Cribari-Neto).

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- Microwaves intensity are not significantly affected by the presence of clouds, so image acquisition is possible in most metheorological conditions and in regions with permanent cloud coverage.
- SAR images can have high spatial resolution, e.g. of less than 1 m, thus making the study of small scale phenomena possible.
- SAR images contain complementary information to that provided by optical images. The selection of frequency band, polarization and angle of incidence in SAR imagery allows the discrimination of different surface properties.

A SAR sensor emits and receives electromagnetic waves of complex nature and, therefore, the received signal can be stored in different formats: complex, intensity, amplitude and phase [22].

In a SAR image, it is possible to distinguish several types of roughness or texture, according to which one can classify the different types of covers:

- Homogenous areas: Surfaces of very little texture; for example, crops, deforestation, and, under some conditions, snow, water or ice.
- Heterogeneous areas: surfaces that display some texture; for example, forests on not very pronounced reliefs, among others.
- Extremely heterogeneous areas: Surfaces with intense texture; for instance, urban areas, among others.

"Texture", in the context of SAR imagery, should be understood as a measure of the number of objects in a cell of the size the of the wavelength employed by the sensor. A fine texture corresponds to a large number of objects per cell, while coarse or extremely heterogeneous textures are those for which only a few objects are counted per cell. The Japanese Earth Resources Satellite JERS-1, for instance, operates on L-Band (1.3 GHz, 23.5 cm wavelength) and the European Remote Sensing Satellites ERS-1 and ERS-2 use C-Band (5.3 GHz, 5.6 cm wavelength).

A problem of paramount importance in the analysis of images is segmentation: the process that divides an image in its constituent parts or objects. Its main goal is to group image areas that have similar characteristics. One of the basic principles in the segmentation process is the detection of discontinuities. *Edges* are the borders of the objects and are therefore quite useful for their segmentation, registration and identification. Edges can be thought as the locations where abrupt changes in intensity or in other important characteristic occur.

The quality of SAR images is degraded by speckle, a degradation which follows from the use of coherent illumination, i.e., when the signal phase is employed in the image formation. Such degradation is characteristic of technologies that employ microwaves, sonar, laser and ultrasound.

The presence of speckle makes edge detection difficult, since most algorithms identify regions using local characteristics. Though speckle should not be regarded as noise, since it has a deterministic nature and is reproducible, from the image practitioner viewpoint it can be considered a random effect and can be conveniently described by stochastic laws; c.f. Richards [24, Sec. 4.3.1]. It is not convenient to only use pointwise information when detecting edges under speckle; it is necessary to analyze the image using sets of pixels that provide local information [15].

Different approaches can be used to locate the edges between regions in a SAR image. A particularly attractive and well performing statistical method was proposed by Gambini et al. [14]. It is based on the family of $\mathcal{G}$ distributions, which can be successfully used to describe areas with different degrees of homogeneity [11,13,18,19].

In this work we consider intensity imagery, described by the $\mathcal{G}_I^0$ law. This distribution is indexed by the number of looks $L \geq 1$, the scale parameter $\gamma > 0$ and the roughness parameter $\alpha < 0$. The former can be controlled when generating the image or in postprocessing stages, and is a measure of the signal-to-noise ratio [24, Sec. 4.3.1]. The value of the roughness parameter is of interest in many applications, since it can be used as an indicator of land type. The scale parameter relates to the relative power between the reflected and incident signals [13].

Fig. 1 presents three different targets and the corresponding values (or range of values) of the roughness parameter (α). Small values of α (e.g., $\alpha < -10$) are associated with homogeneous areas, such as pastures. Values of $\alpha \in [-10, -4]$ are characteristic of heterogeneous regions, for example forests. Finally, larger values of α (say, $-4 < \alpha < 0$) are observed in extremely heterogeneous areas, such as urban regions [6,19].

Our chief goal is to develop and assess new methods for edge detection in SAR images using computationally efficient nonparametric statistical inference. Gambini et al. [14] showed that a method based on maximum likelihood, which is presented in Section 3.1, is more precise than four commonly used techniques: two based on raw data (maximum discontinuity and fractal dimension) and two based on estimates (maximum discontinuity and anisotropic smoothed