Original paper

Edge enhancement in multispectral satellite images by means of vector operators

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Received: May 14, 2013; accepted: December 02, 2013; published on line: July 01, 2014

Resumen

El realce de bordes es un elemento de análisis para entender la estructura espacial de imágenes de satélite. Se presentan dos métodos para extraer los bordes de imágenes multiespectrales de satélite. Una imagen multiespectral se modela como un campo vectorial de un número de dimensiones igual al número de bandas en la imagen. En este modelo, un pixel se define como un vector formado por un número d elementos igual al número de bandas. Se aplican dos operadores vectoriales a tal campo vectorial. En nuestro primer método, extendemos la definición de gradiente. En esta extensión, se obtiene el vector diferencia del pixel central de una ventana con los pixels vecinos. Se genera entonces una imagen multiespectral donde cada pixel representa el máximo cambio en la respuesta espectral en la imagen en cualquier dirección. A esta imagen se le denomina el gradiente multiespectral. El otro método considera la generalización del Laplaciano por medio de la transformada de Fourier h-dimensional. A esta imagen se le denomina el Laplaciano multiespectral. Los operadores vectoriales realizan una extracción simultánea del contenido de bordes en las bandas espectrales de la imagen multiespectral. Nuestros métodos son libres de parámetros. Nuestros métodos trabajan para una imagen multiespectral de cualquier número de bandas. Se discuten dos ejemplos que involucran imágenes multiespectrales de satélite a dos escalas. Comparamos nuestros resultados con procedimientos de realces de bordes ampliamente empleados. La evaluación de los resultados muestra un mejor comportamiento de los métodos propuestos comparados con los operadores de bordes ampliamente usados..

Palabras clave: detección de bordes, imagen multiespectral, realce de borde, operador vectorial.

Abstract

Edge enhancement is an element of analysis to derive the spatial structure of satellite images. Two methods to extract edges from multispectral satellite images are presented. A multispectral image is modeled as a vector field with a number of dimensions equal to the number of bands in the image. In this model, a pixel is defined as a vector formed by a number of elements equal to the number of bands. Two vector operators are applied to such vector field. In our first method, we extend the definition of the gradient. In this extension, the vector difference of the window central pixel with neighboring pixels is obtained. A multispectral image is then generated where each pixel represents the maximum change in spectral response in the image in any direction. This image is named a multispectral gradient. The other method, considers the generalization of the Laplacian by means of an η-dimensional Fourier transform. This image is named a multispectral Laplacian. The vector operators perform a simultaneous extraction of edge-content in the spectral bands of a multispectral image. Our methods are parameter-free. Our methods work for a multispectral image of any number of bands. Two examples are discussed that involve multispectral satellite images at two scales. We compare our results with widely used edge enhancement procedures. The evaluation of results shows better performance of proposed methods when compared to widely used edge operators.

Key words: edge detection, multispectral image, edge enhancement, vector operator.

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Introduction

Edge detection has been undertaken for gray-level and color images using a number of methods and procedures. Most of the techniques published in the scientific literature in the last years deal with color images.

Well-established methods such as Kirsch, Sobel, Gradient and Laplacian operators have been widely used to extract edges in gray-level images (Pratt, 2001). Bowyer and co-workers (2001) provided a detailed account of a number of edge operators in gray images. The reviewed operators carry a set of parameters that needs to be defined in terms of heuristic criteria. Ground-truth images were used to derive a classification of edge operator performance (Bowyer *et al*., 2001). A deformable contour, defined by a wavelet snake, is designed to identify the boundary of pulmonary nodules in digital chest radiographs (Yoshida, 2003). In this work (Yoshida 2003), a multi-scale edge representation is obtained by means of the wavelet transform; this produces, however, fragmented edge segments. Therefore, a wavelet snake was used to produce a smooth and closed contour of a pulmonary nodule.

Other methods to detect edges in gray-level images use fuzzy logic. Segmentation of a fuzzy image into regions of similar image properties was achieved by means of a fuzzy procedure (Bigand *et al*., 2001). This method works with fuzzy-like and noisy images. Zero crossings that correspond to gradient maxima were obtained by means of the cosine transform in noisy images (Sundaram, 2003). This scheme favors the detection of weak edges in background noise and suppresses false edges.

The modeling of natural RGB images as vector fields has been exploited to detect edges in color images (Koschan and Abidi, 2005; Evans and Liu, 2006). In their studies, the authors (Koschan and Abidi, 2005) provide an overview of color edge detection techniques, and, in particular, generalizations of Canny and Cumani operators to color spaces were discussed with examples. Evans and Liu (2006) provide a review of color edge detectors.

A parameter-free approach could be obtained when an automatic determination threshold was calculated using a model-based design (Fan *et al*., 2001). With this approach, a color-image edge operator is derived. Cellular neural networks applied to color images resulted in a model to detect edges (Li *et al*., 2008). This model was successfully applied to RGB images with color test patterns. In addition to these results, the authors provided a detailed revision of color edge detection techniques.

Recent advances in edge enhancement for color images show clear advantages over methods for mono-spectral images (Xu *et al*., 2010; Chen and Chen, 2010; Nezhadarya and Kreidieh, 2011; Gao *et al*., 2011; Chu *et al*., 2013). Color images are increasingly used in many applications such as surveillance, computer vision and robotics. Multispectral satellite images are available at several scales. For these two groups of images, edge enhancement is an element of structural analysis.

A general method is needed that works for any number of bands, with no parameters and a reasonable computing time. To fulfill such goal, we model a multispectral satellite image by means of a vector field. The dimension of this field equals the number of bands of the image. Upon this field, we may apply vector operators. We compare our results with those obtained from conventional edge operators (Pratt, 2001; Bowyer *et al*., 2001). We carry out a detailed evaluation of our results. Such evaluation includes qualitative and quantitative analysis. Our evaluation shows a clear improvement with respect to conventional edge operators.

Study area and data

Two multispectral satellite images were used to test the goodness of our method at different scales. Both images cover a portion of Mexico City where the runaways of an airport are clearly visible. One of the images is formed by the visible and near infrared (VNIR) bands of the Advanced Spaceborne Thermal Emission and Reflection Radiometer sensor (ASTER) on board Terra satellite (Figure 1). The four bands of the IKONOS sensor (Figure 2) form the other image. Table 1 provides basic parameters of these images.

Table 1. Basic parameters of multispectral images.

	ASTER	IKONOS
Acquisition date	July 7, 2003	June 14, 2006
Pixel size (m^2)	15 · 15	4 · 4
Dimension (pixels)	500 x 500	1200 x 1200
Bands (μm)	1) 0.52-0.60 2) 0.63-0.69 3N) 0.76-0.86 3B) 0.76-0.86	1) 0.45-0.52 2) 0.52-0.60 3) 0.63-0.69 4) 0.76-0.90

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