Morphological Change of a Scene Employing Synthetic Multispectral and Panchromatic Images

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Abstract. Climate change has produced transformations in the coastal zone of Tamaulipas State. Such changes include modifications to coastline and transformations to texture-relief and texture of the zone. In this work, high resolution panchromatic SPOT images have been employed to quantify such modifications. A synthetic multispectral image is used to validate our results. To quantify the texture-relief and texture, the multi-spectral image is modeled as a vector field of as many dimensions as bands of the image. Upon this field, the vector operators divergence and laplacian are applied. Results are presented for an area of Tampico-Altamira, details of the methodology are shown and results are discussed.

Keywords: vector field, vector operators, texture change, texture-relief change.

1 Introduction

Global warming has produced changes in sea level, in wind patterns and in rain patterns. Such changes have modified the morphology of coastal zones [1]. This includes modifications of the coastline and alterations in texture pattern of a scene. A change detection technique is required to quantify the modification of such morphology. An ample review of change detection techniques has been published by several authors [2, 3]. In this review a convenient definition of change detection is introduced. The basic conditions that a change detection investigation should satisfy are discussed as well. In some instances, the natural or anthropogenic causes of change detection should be quantitatively determined.

The use of polarimetric radar has demonstrated good capability to segment land masses and water masses [4]. This segmentation leads to the detection of the coastline. The use of recent procedures of analysis was employed to detect the coastline with good results [5, 6, 7, 3]. On the grounds of a variant of the principal component analysis, the coast line was detected [8]. In a review paper, the state of the art for the detection, extraction and supervision of the coastline is presented [9]. This article included a detailed recollection of remote sensing techniques using different sensors, from aerial photography to radar imagery. Morphologic modifications of the coastline have been studied with various methods [10, 11, 12, 13, 3].

E. Bayro-Corrochano and E. Hancock (Eds.): CIARP 2014, LNCS 8827, pp. 1006–1013, 2014.

Radar images can be used to determine a change detection phenomenon such as change of soil moisture in agricultural areas [14]. Soil penetration by a radar signal depends on its wavelength and on the volumetric dielectric constant. This constant depends on soil moisture. The basic hypothesis is that soil moisture variations produce a change in penetration depth. This generates a change on the phase-scattering from the soil moisture content. The phase-scattering was best observed in C-band cross-polarization of polarimetric radar images. A detailed review on the use of SAR images to observe change detection and optimal decision on a scene is provided by Hachicha and Chaabane [15].

To detect possible changes in a scene, two images are acquired at different times. The difference image is modeled using a Poisson's mixture model [16]. On the grounds of such model a threshold is then introduced to detect the pixels associated to change. A set of synthetic and satellite images is used to demonstrate the validity of the method. An error analysis is introduced and a visual inspection is performed to evaluate the results.

Several methods based on vector operators were developed to quantify the morphology of a scene [17, 18, 19]. From the application of such vector operators to multispectral images, it is possible to derive the texture and texture-relief of the scene.

In this research we propose the use of synthetic images and stereoscopic pairs to study morphologic changes in the coastal zone of Tampico-Altamira. Such images are from the same scene but acquired in different times. We propose the application of vector operators to the vector field defined by the synthetic and the stereoscopic pair. From such application we derived texture changes and texture-relief changes experimented by the scene in a certain time span. The synthetic image is used to validate our results.

2 Materials and Methods

2.1 Materials

A set of high resolution SPOT images of the coastal zone of Tampico-Altamira were acquired by means of a covenant with the Army Department. Two high resolution panchromatic images that form a stereoscopic pair define the set. An RGB synthetic multispectral image was acquired from internet. This image depicts a scene observed at noon and in the afternoon. Table 1 shows technical details on the stereoscopic pair and the synthetic image.

Table 1. Technical details of images

Image	Dimension (pixels)	Pixel (m^2)	Date	View
Tampico-Altamira	$12,000 \times 12,000$	5×5	March 13, 2005	Left
Tampico-Altamira	$12,000 \times 12,000$	5×5	January 20, 2006	Right
Synthetic	$4,077 \times 4,092$	0.23×0.23	n/a	Noon
Synthetic	$4,077 \times 4,092$	0.23×0.23	n/a	Afternoon

2.2 Methods

The study of morphologic changes in the coastal zone of Tampico-Altamira is divided in two categories. (A) Changes of texture of the scene. (B) Modifications of the texture-relief of the scene. A multispectral image is modeled as a vector field of as many dimensions as bands of the image [19]. Upon this vector field, the divergence and the laplacian vector operators are applied to derive the above mentioned changes. The panchromatic images were orthorectified using the ephemerides of the satellite. Both, the synthetic and the panchromatic images were radiometrically normalized. A registration procedure was applied to the images that form the setereoscopic pair. The synthetic images were already registered. The following sections describe in detail each of the above mentioned categories.

2.3 Definition of Change Detection

Change detection is the process of identifying differences in the state of an object or phenomenon by observing it at different times [2]. Satellites images are suitable for change detection due to repetitive data acquisition, synoptic view and digital format [20]. A scene may be described by morphologic descriptors: area, perimeter, fractal dimension, texture and texture-relief. We deal with the last two descriptors.

A scene may experiment modifications caused by natural causes such as climate change or artificial forces induced by anthropogenic activity [2, 20]. Change detection may provide the following information: (i). Area change and change rate. (ii). Spatial distribution of changed types. (iii). Accuracy assessment of change detection results. Change detection may require two preprocessing steps: (i). Orthorectification and image registration. (ii). Radiometric and atmospheric correction.

2.4 Change of Texture

The Divergence operator applied to the vector field defined by the multispectral image produces a texture map of the scene [17].

Let $\mathbf{U} = \mathbf{u}(x_1,x_2, \ldots x_n)$ be the vector field associated to an n-band multispectral image [Lira, 2010]. The divergence operator [19] of the n-dimensional vector field $\mathbf{U}$ is defined as

$$\nabla \cdot \mathbf{U} = \sum_{i=1}^{n} \frac{\partial u_{x_i}}{\partial x_i} \tag{1}$$

Where x_i is the i^{th} coordinate of a Cartesian coordinate system of an Euclidian space, and u_{xi} is the component of the vector field $\mathbf{U} = \mathbf{u}(x_1,x_2, \ldots x_n)$ along the direction defined by x_i.

The images considered in this research are from different dates (Table 1). The stereoscopic pair may be considered as a multispectral image composed by two bands. Therefore, the associated vector field is bi-dimensional. The synthetic image from two dates may be considered as a 6-band multispectral image. Therefore, the vector field is 6-dimensional. The divergence operator was applied to such vector fields.

The synthetic image is used to test the validity of our method. Figure 1 show a mosaic of the synthetic image at noon, at afternoon and an overlay of edges depicting the change the synthetic image experienced as a result of different illuminating conditions. The edges from the divergence operator were overlaid upon the afternoon image. The zones of varying illumination are delineated by the edges. Therefore, the resulting map from the divergence shows the texture changes that the scene experienced in the time span of the images.

The panchromatic images posses a high resolution, thus, the resulting map shows details of the texture change the scene experienced in a time span of almost a year. Figure 2 show the map of texture change produce by the divergence operator applied to the stereoscopic pair.

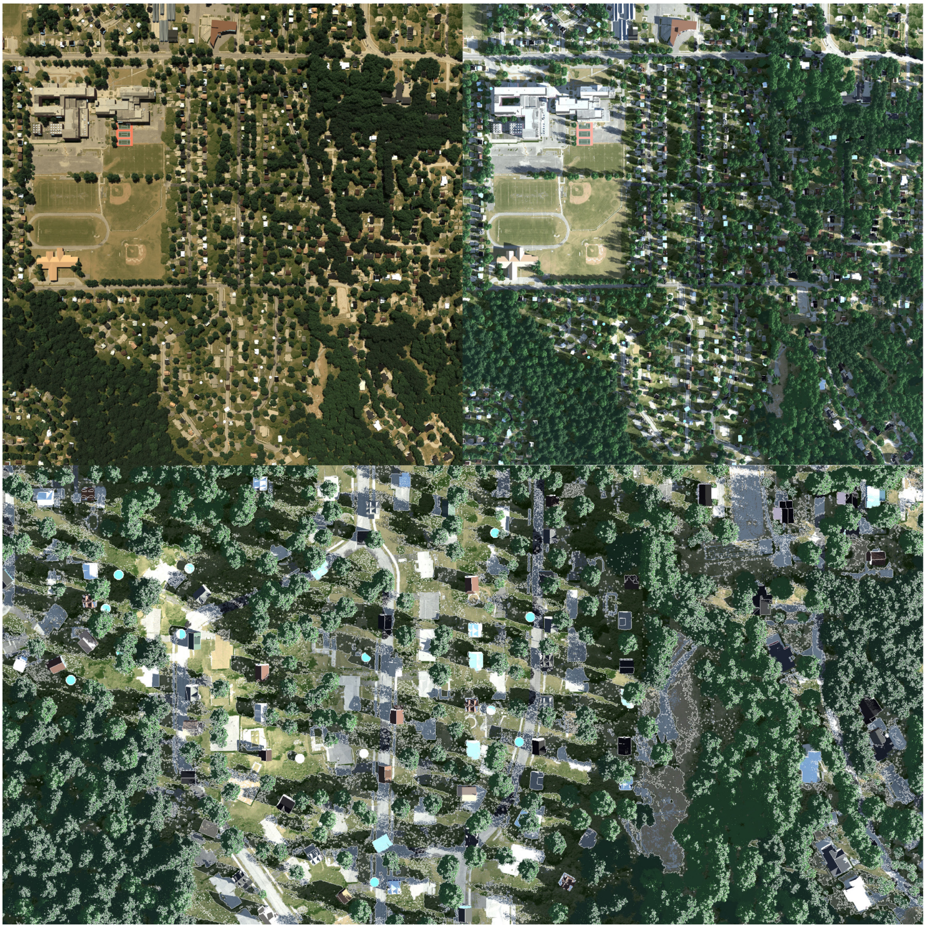

Fig. 1. Mosaic of synthetic multispectral image. Upper row: image at noon (left), image at afternoon (right). Lower row: amplification of edges from the divergence operator overlaid with the afternoon image. Texture changes are delineated by the edges.

2.5 Change of Texture-Relief

Changes of texture-relief may be obtained by means of two methods. (i) The application of principal component analysis (PCA) to the stereoscopic pair of the scene [18]. The second principal component carries the texture-relief of the scene. (ii) The application of the vector laplacian to the stereoscopic pair. In this work we present results from the laplacian (Figure 2). Results from the second principal component were published in [18].

Let consider the stereoscopic pair as a two-band multispectral image. Hence, each band refers to the same scene but correspond to different time of acquisition. Let $\mathbf{f}(\mathbf{q})$ be the vector field associated to a multispectral image [21]. The vector laplacian in $\mathbb{Z}^n$ of the vector field $\mathbf{f}(\mathbf{q})$ is therefore

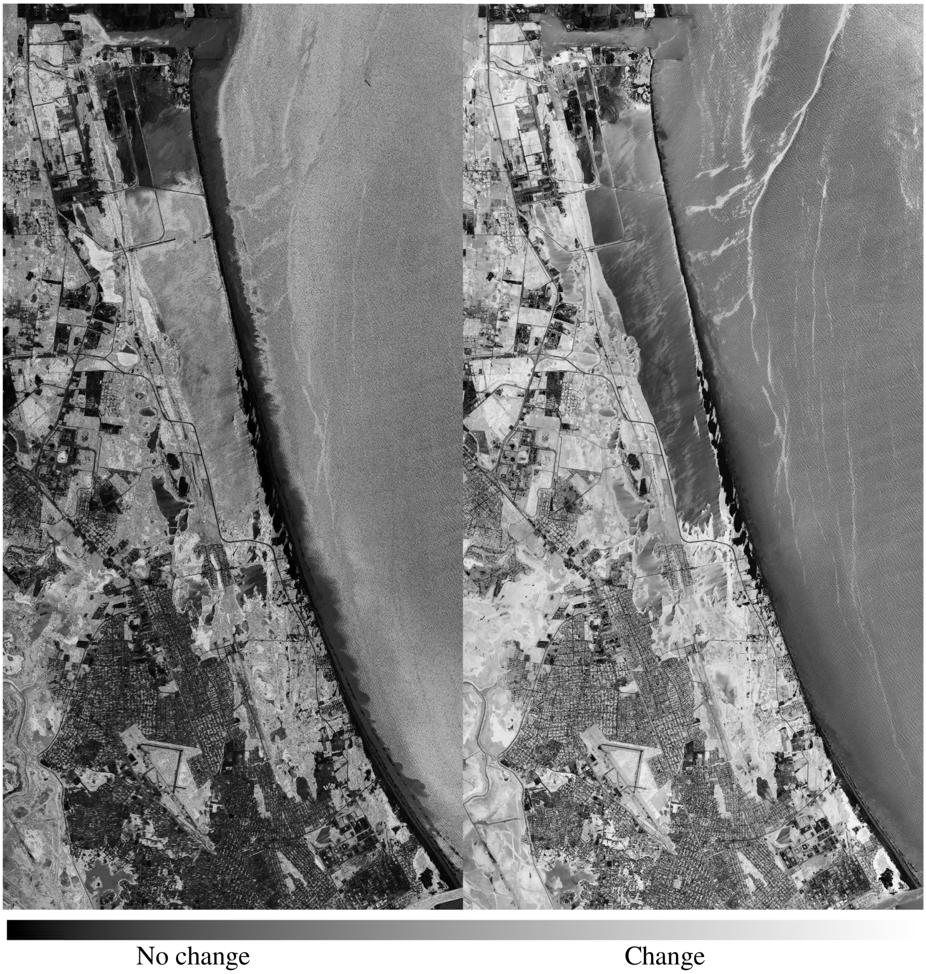

Fig. 2. Texture change by divergence operator are depicted on the left image and texture-relief change by laplacian operator are depicted on the right image. The gray scale bar associates gray tone with morphologic change.

$$\mathsf{F}[\nabla^2 \mathbf{f}(\boldsymbol{q})] = -(2\pi)^2 |\boldsymbol{k}|^2 \mathbf{F}(\boldsymbol{k}) \quad (2)$$

Where the symbol F stands for Fourier transform, $\mathbf{F}(\boldsymbol{k}) = \mathsf{F}[\mathbf{f}(\mathbf{q})]$, $\mathbf{q}$ is the vector associated to a pixel of the multispectral image, and $\mathbf{k}$ is the vector of spatial frequencies in the Fourier domain. Equation (2) implies that the vector laplacian is an n-dimensional vector field. The bands of such field are averaged to produce results in a single gray level image (Figure 2).

The high resolution of the panchromatic stereoscopic pair produced detailed results. The images that form the stereoscopic pair are acquired in different dates (Table 1). The difference in time is close to one year. Therefore, the laplacian show changes of texture-relief of the scene in such time span (Fig. 2).

3 Results and Discussion

The algorithms of the vector operators used in this research were developed with Delphi language working under Windows 7. Both operators work for multispectral images up to ten bands. The limit of the size of the images is driven by the memory of the PC. For an image of four bands and 8,000 x 8,000 pixels the time of execution is two minutes for divergence operator and four minutes for laplacian operator.

The texture and texture-relief are scale dependent and no field work device is available to measure such morphologic features. In addition to this, there is no published research in the scientific literature describing a method to quantify changes in texture and texture-relief. Therefore, a synthetic image, generated under controlled conditions is required to validate our results. On the grounds of results using a synthetic image and a general visual inspection of texture maps we produced the discussion of the following two sections.

3.1 Changes in Texture

To derive a map of texture changes the divergence operator was applied to the images that form the stereoscopic-panchromatic pair. This result depicts, in one single image, the texture changes the scene experienced in a time span of eight months. A gray scale, included in figure 2, associates gray level to change texture. In this time span the scene has experienced morphologic changes that imply a change in texture. Texture changes may occur from smooth texture to rough texture, with no change in texture, and from rough texture to smooth texture. Such changes are depicted in the texture map produced by the divergence operator (Fig. 2). The areas of the scene where no texture change occurred appear in dark gray tones. The greater the texture changes the lighter the gray tone.

3.2 Changes in Texture-Relief

The topography of the scene presents a variation that is spatial variant across the scene. The relief of this topography is related to the texture of the scene. A small varying relief is associated to a smooth texture. A high varying relief is associated to a rough texture. This association is dubbed the texture-relief. The area of study has subtle changes in topography. The laplacian operator enhances such changes and produces an image of texture-relief. In the time span of the panchromatic images, the scene experiment subtle changes. Panchromatic images posses a high spatial resolution (Table 1). Therefore, to derive a map of texture-relief, the laplacian operator was applied to the stereoscopic pair formed by the panchromatic images. The resulting texture-relief map produced by the laplacian operator show the changes from dark gray to light gray (Fig. 2). The darker the gray tone, the greater the changes.

4 Conclusions

Two methods have been developed to study and quantify the morphology of a coastal zone in Nor East México. From the ensemble of morphologic descriptors, our work deals with texture change and texture-relief change. These two aspects of morphology require attention to understand the evolution of a scene. To this end, high resolution panchromatic images were employed. The difference in time for the acquisition of such images is close to eight months. In this time span, the scene experimented morphologic modifications. To quantify such modifications, the multispectral synthetic images and the panchromatic pairs were modeled as a vector field of a number of dimensions equal to the number of bands. A six-dimensional vector field for the multispectral synthetic images and a two-dimensional vector field for the panchromatic pair. The synthetic images were used to validate the results of our proposed methods. It is important to mention that the vector field of the stereoscopic pair is formed by two images of the same wavelength of the same scene but from different dates. For multispectral images, the vector field is formed by bands of several wavelengths, of the same scene and for different dates. The application of the vector operators divergence and laplacian allows the quantification of morphologic changes that the scene has experienced in a certain time span.

Acknowledgment. The authors thank the Army Department for the free delivery of the Spot images.

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