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REMOTE SENSING FEATURE DETECTION AND GEOINFORMATION RETRIEVAL VIA MULTISCALE 2D GABOR WAVELET TRANSFORM

Abstract:

Remote sensing involves observation, acquisition and processing of information detected and measured from airborne or spaceborne platforms. The structural information of objects such as landmarks, highways, bridges, mountains, oceans, rivers, lakes, living creatures and moving targets could be represented by edges and contours based on the high-spatial resolution remote sensing images. The geographic information system (GIS) has been widely adopted to exhibit features, patterns, and trends on the surface of the earth. The data sources from aerial photos and satellite images are typically stored as raster images that contain composite tristimulus color values of red, green and blue (RGB). It allows people to visualize, analyze, process, interpret and archive data to synthesize the boundaries, interactions and relationships of the features, patterns, and trends. Remote sensing could be either passive or active. The passive sensing system identifies natural radiation via visible light imaging or infrared photography. The active sensing system emits its own energy to scan objects so that the reflected or backscattered radiation can be detected and measured, such as Radar or Lidar (Radio or Light Detection and Ranging). To achieve better data abstraction and management with respect to spatial 2D data analysis, integration of geovisualization and geocomputation can be introduced for dynamic data exploration so that the latent interactions could be discovered. Edges are critical features of structural information. Numerous approaches have been designed for detecting edges of high spatial resolution images using gradient based algorithms. However, most methods are sensitive to noises. The 2D Gabor filter is then presented to extract and differentiate the crucial structural information via parametric optimization, where Gabor wavelet transform will be employed for edge detection and contour tracing using convolution operation of each of three primary color components of digital images with the 2D Gabor wavelet in the frequency domain. It has been shown that multiscale Gabor wavelets are suitable for segmenting remote sensing images to explore intrinsic geographical information. Numerical simulations on diversified landscape aerial images have been carried out to show the impact of the proposed approach on spatial information analysis.

Keywords:

Remote Sensing, Wavelet Decomposition, Multiscale Gabor Transform, Edge Detection, Soft Thresholding

Introduction

In the geographic information system, visualization of spatial data is a complex process to interpret remote sensing images using edges, contours, patterns, features, interactions and relationships, as well as potential trends being predicted. Remote sensing involves numerous useful tasks such as environment monitoring, weather forecasting, natural resource management, ground surveillance, and military operation, etc. Geovisualization integrates geospatial information being collected for further data analysis, exploration and decision making by interactive visualization, where visualization is implemented using computer graphic techniques to explore large amount of abstract data [1-2].

Geographical information exists in multiple forms such as cartographies, images, and texts. Advantages and limitations of both geographical and textual information retrieval systems are discussed in dealing with geovisualization. A new retrieval model integrates coordinate-based geographical indexing with keyword based vector space model to represent information space. Document ranking is measured by degree of relevance in both the spatial domain and thematic domain [3]. For large scale satellite images, it is inevitable that images will be affected by various factors. To minimize the impact of atmosphere medium dispersing, segmentation via K-means clustering is applied which requires that number of clusters for partitioning be specified and its distance metric be defined to quantify relative orientation of objects. To reduce computational complexity, tristimulus values are selected to represent the three layer color space [4]. Spatial digital image analysis has a vital role in the information decision support systems, especially for regions frequently being affected by hurricanes and tropical storms (e.g. New Orleans). For aerial imaging based pattern recognition, it is unavoidable that these images will be affected by atmospheric medium dispersing. Image denoising is necessary to remove noises and retain important signatures of digital images. As a nonlinear wavelet technique, wavelet decomposition into multiple scales is effective to denoise blurring spatial images. The reconstructed image is subject to object recognition using nonlinear K-means clustering, while quantitative measures are also introduced for the accurate decision support [5]. The enhanced fractional snow-covered area (SCA) estimation for the boreal forest zone is presented. It uses weather station data along with spaceborne synthetic aperture radar (SAR) imagery and leads to significantly improved estimation accuracy. Satellite wide-swath radar-based remote sensing of snow cover in the snow-melt season is explored across regions of mountainous, open, and forest areas. The predominant aspect lies in the large variation at the radar incidence angle. The incidence angle variation, operational implementation and error propagation analysis are involved. The correlation between topography and SCA estimation is examined which lays foundation for operational SCA estimation on boreal forest zone using wide-swath SAR data [6-7]. Remote sensing is critical to preserve environment in tropical and mountain regions. Image segmentation using K-Means clustering is generally applied to partition information into diverse clusters. Each pixel has a degree of belonging to multiple clusters, so fuzzy K-Means clustering is introduced to depict belongings using fuzzy memberships. Quantitative measures are proposed to identify the actual number of clusters to enhance decision support accuracy and optimize K-Means clustering [8]. It is essential to determine whether pixels on an aerial or satellite image should be classified as an object or background. A newly developed object extraction is made based on fuzzy topology. Two optimal threshold values are proposed for determining the interior, boundary, and exterior of the fuzzy object. The developed object extraction method is applied to boulder extraction from aerial images. The overall quality of object extraction is thus improved greatly [9].

The advent of computerized numerical simulation provides an opportunity for the interactive geovisualization. Integration of geovisualization and geocomputation is necessary due to the rapidly increasing computation power. The dynamic approaches are more feasible for technology integration online for data abstraction and latency discovery. For instance, edges are vital features to describe the structural information for high spatial resolution remote sensing images. Edge features define boundaries between ground objects in high spatial resolution images. A novel method to detect edges is introduced using frequency domain analysis where both Fourier transform and 2D Gabor filter are applied [10]. The Gabor filter is applied also using discrete wavelet transform for edge detection and contour tracing on true color images, whose wavelet functions provide high resolution in both spatial and frequency domains. To generate more accurate outcomes, integration of adaptive contrast stretching and Gabor wavelet transform is properly carried out for edge detection and contour tracing on broadly selected images. The mixture of true color components (red, green, and blue) gives rise to an overall appeal with better visual effect and color balance by rendering three specific colors. Edges, contours and boundaries could be detected in various ways with respect to intensity changes. To overcome drawbacks of edge broken and false detection among classical approaches, artificial intelligence is employed such as Ant Colony Optimization (ACO) so as to avoid information loss and feature deformity. Both visual appealing and quantitative metrics are improved using the proposed approach [11]. In this article, numerous aerial images with various concentrations are selected, so as to verify the role of 2D Gabor multi-scale wavelet algorithm on remote sensing edge detection.

Multi-Scale Gabor Transform

The Gabor filter consists of a complex sinusoid carrier and a Gaussian shaped envelope. For 2-dimensional cases, the spatial domain Gabor filter h(x,y) acts as a Gaussian kernel function modulated by a sinusoid plane wave. Specifically the 2D Gabor filter is the product of a complex sinusoid function and an elliptical Gaussian function. Define s(x,y) as a complex sinusoid carrier and g(x,y) as a 2D Gaussian shaped envelope, then we have (1-3), where two separate functions are located as the real and imaginary parts of the complex function.

$$h(x,y) = s(x,y)g(x,y) \tag{1}$$

$$s(x, y) = e^{j2\pi(u_0 x+v_0 y)} = \cos 2\pi(u_0 x+v_0 y) + i\sin 2\pi(u_0 x+v_0 y) \tag{2}$$

$$g(x, y)=\frac{1}{2\pi\sigma_x\sigma_y} e^{-(\frac{x^2}{2\sigma_x^2}+\frac{y^2}{2\sigma_y^2})} \tag{3}$$

where σ_x and σ_y represent the standard deviations in x and y coordinates, u_0 and v_0 are the spatial frequencies of the 2D Gabor filter. The 2D Gabor filter is formulated as (4):

$$h(x, y)=s(x, y)g(x, y)=\frac{1}{2\pi\sigma_x\sigma_y} e^{-(\frac{x^2}{2\sigma_x^2}+\frac{y^2}{2\sigma_y^2})} e^{j2\pi(u_0 x+v_0 y)}$$

$$=\frac{e^{-(\frac{x^2}{2\sigma_x^2}+\frac{y^2}{2\sigma_y^2})}}{2\pi\sigma_x\sigma_y}[\cos 2\pi(u_0 x+v_0 y) + i\sin 2\pi(u_0 x+v_0 y)] \tag{4}$$

The frequency response of the 2D Gabor filter has the frequency shifts along the u coordinate and v coordinate. In the frequency domain, it is expressed in (5).

$$H(u, v) = G(u-u_0, v-v_0) \tag{5}$$

Via convolution, H(u, v) can also be formulated as (6):

$$H(u, v)=2\pi\sigma_u\sigma_v e^{-2\pi^2[(u-u_0)^2\sigma_u^2+(v-v_0)^2\sigma_v^2]} \tag{6}$$

Here σ_u and σ_v are the standard deviations.

$$\sigma_u=\frac{\sigma_x}{2\pi};\ \sigma_v=\frac{\sigma_y}{2\pi} \tag{7}$$

Both rotation and dilation operations are conducted on the Gabor function to generate the 2D Gabor wavelets as (8).

$$g_{mn}(x, y) = g(x', y') / \alpha^m \tag{8}$$

For m = 0, 1, ..., M−1 and n = 0, 1, ..., N−1, the scaling factor is defined as $s = \alpha^{(-m)}$ (α>1)) and the phase factor is defined as $\theta_n = n\pi / N$, which represents the orientation of the sinusoidal plane wave, where M and N reflect the total number of scales and orientations. Upon rotation, resulting (x', y') is formulated as (9) or (10).

$$\begin{bmatrix} x' \\ y' \end{bmatrix} = \begin{bmatrix} \cos\theta_n & \sin\theta_n \\ -\sin\theta_n & \cos\theta_n \end{bmatrix} \begin{bmatrix} x \\ y \end{bmatrix} \quad (9)$$

$$x' = x\cos\theta_n + y\sin\theta_n \text{ and } y' = -x\sin\theta_n + y\cos\theta_n \quad (10)$$

A typical set of true color aerial images being obtained are now subject to Gabor edge detection. Each of three tristimulus (red, green and blue) components has the intensity distribution ranging from 0 to 255. Soft thresholding is applied to each component whose composite effect leads to true color image retrieval. Since Gabor wavelets are symmetrically formulated, θ_n must be specified in advance where an evenly sampled space is scheduled within [0, π]. The Gabor filter contains the real and imaginary components representing primary and secondary directions. Sixteen Gabor wavelets are generated and the 2D Gabor wavelet transform is then applied for edge detection on remote sensing images.

True Color RGB Model

In the true color system, each of 3 colors (Red – Green - Blue) represents a primary spectral component in the Cartesian coordinate system. Each of the three intensity components in the true color space could be computed and analyzed independently before the composition is reached. In the true color subspace, each color is uniquely mapped into a cube in which the RGB values lie at three corners; black locates at the origin and white locates at the corner opposite to the origin; while other three colors (cyan, magenta, yellow) locate at the rest three corners. By convention, the lowest value corresponds to the color of black and the highest value corresponds to the color of white. The grey scale lies along with the main diagonal that links black and white corners. Every color acts as a vector on or inside the cube pointed from the origin. Image quantization serves as the A/D transition between continuous image values and its digital integer equivalent. Diverse percentage combination of red, green and blue will generate a variety of true colors. The projection of RGB true color intensity components onto the leading diagonal gives rise to the grayscale image. The intensity component is the composite color image from three primary image planes. Unlike the gray scale images, contour detection of true color images is seldom conducted, thus the new proposed approach will be implemented on feature detection of the RGB color images.

Edge Detection of True Color Aerial Images

Gabor wavelet transform is presented in this session for edge detection on a set of selected true color aerial images. Without loss of generality, diverse types of remote sensing images are chosen and processed according to computer-aided visualization.

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Information visualization is based on the combination of signal processing and image processing as well as computer vision. For example, the shape of bridges and highways can be conveyed by edges and linkages; the pattern of skylines, coastlines, islands and mountains can be conveyed by the contours. Surface reflectance and surface coloration will be depicted according to the diversity of objects (e.g., water, snow, vegetation, terrain). Multi-scale representation of each component (R, G, B) of remote sensing images is conducted via Gabor wavelet with different levels of details. A higher degree of detail is needed to illustrate the foreground than background with the larger perspective magnification. Using the multi-scale Gabor wavelet filter edge detection algorithm, the true color images at specified scales are generated based on the source remote sensing images. Soft thresholding is applied subsequently for noise rejection and edge detail enhancement. Image retrieval can be made eventually by reconstructing the downsized (red, green and blue) images at different scales being processed into a composite image. In Figs. 1-10, remote sensing images of some typical landmarks are processed using Gabor wavelet filter edge detection. Three tristimulus color components are processed independently ahead of image reconstruction.

Figure 1: Gabor Wavelet Detection (Mackinac Bridge and Upper Peninsula)

Figure 2: Gabor Wavelet Detection (Suspension Bridges of UK)

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Figure 3: Gabor Wavelet Detection (Suspension Bridges of NYC Area)

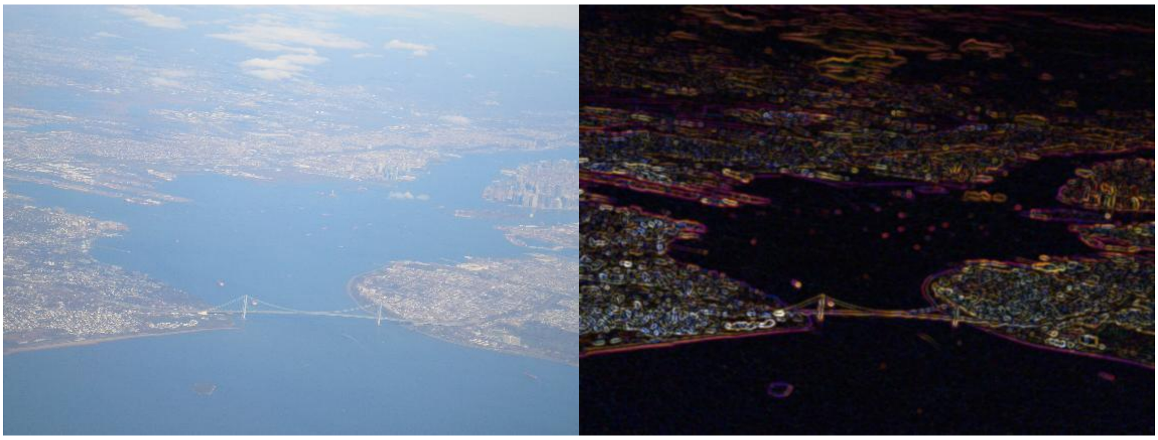

Figure 4: Gabor Wavelet Detection (Bird Eye View of DC)

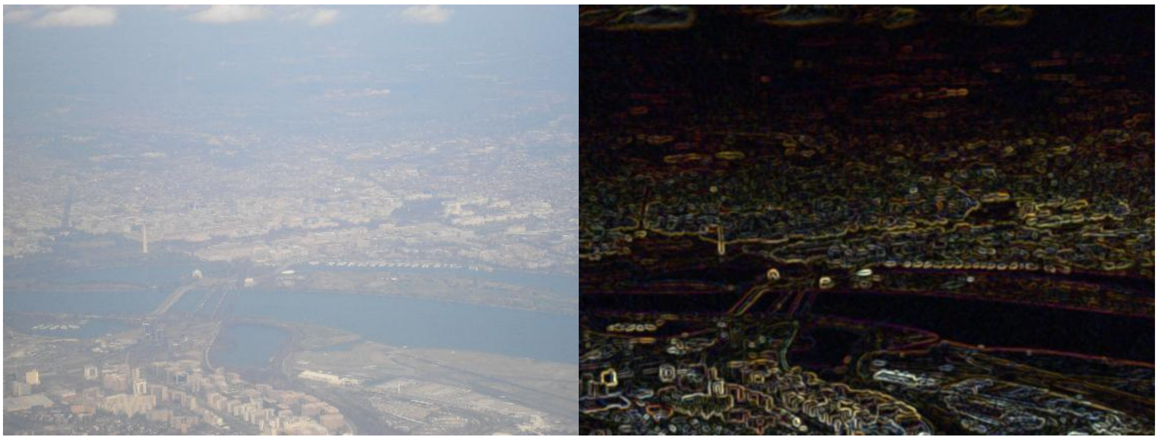

Figure 5: Gabor Wavelet Detection (Bird Eye View of NYC)

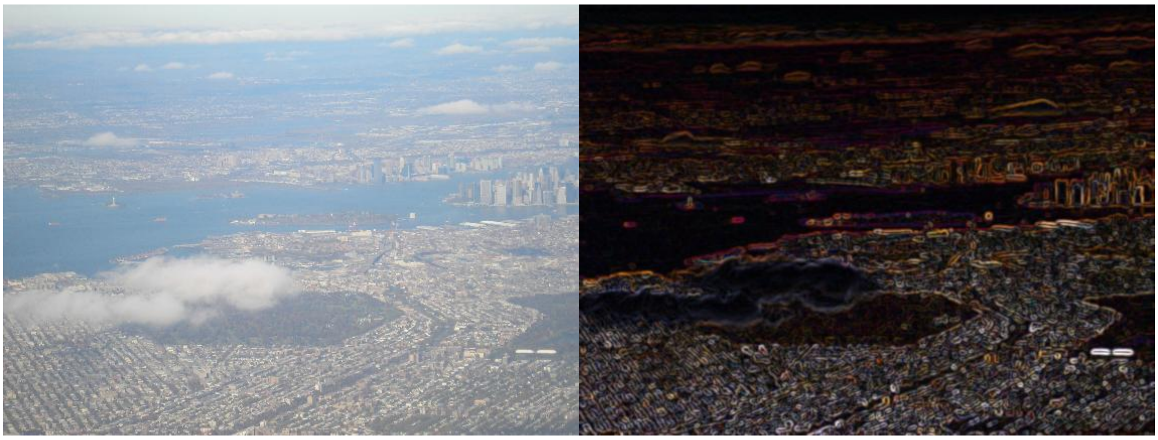

Figure 6: Gabor Wavelet Detection (Bird Eye View of New Orleans)

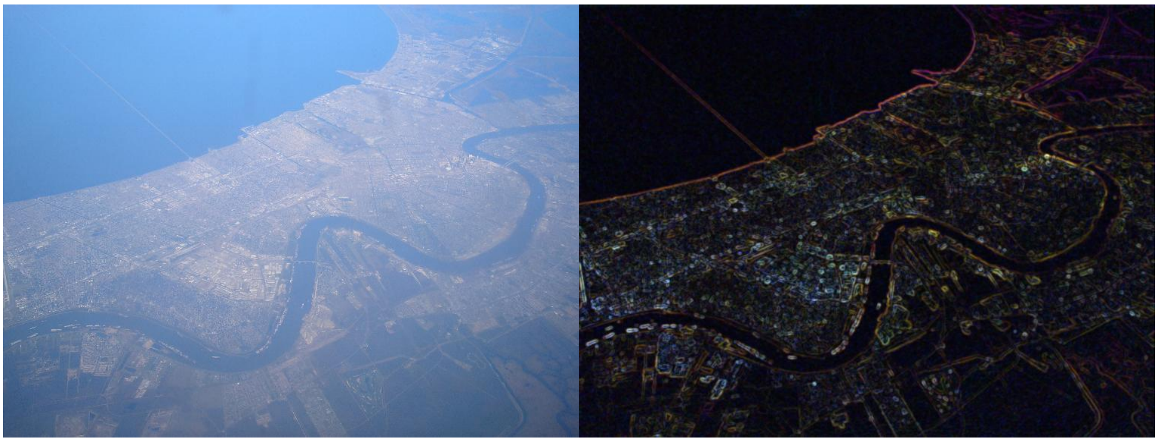

Figure 7: Gabor Wavelet Detection (Bird Eye View of Florida Keys)

Figure 8: Gabor Wavelet Detection (Bird Eye View of Alps)

Figure 9: Gabor Wavelet Detection (Bird Eye View of Andes)

Figure 10: Gabor Wavelet Detection (Bird Eye View of Appalachian)

In Figures 1-3, Gabor edge detection on typical aerial images covering bridges, open water and major terrains are shown. In Figures 4-6, Gabor edge detection on typical aerial images with both landmarks and open water in metropolitan cities are shown. In Figure 7, Gabor edge detection on the unique aerial image of Florida Key between Gulf of Mexico and Atlantic Ocean is shown. In Figures 8-10, Gabor edge detection on the unique aerial image of snow Mount Alps, Mount Andes and Mount Appalachian are shown. From all these typical tristimulus aerial images, the true color edges and contours of diverse dominating objects are clearly extracted using the proposed 2D Gabor wavelet approach. Better visual appeal and color balance are achieved using the composite true color edge components by rendering three specific colors rather than the gray scale component exclusively. It has depicted that 2D Gabor wavelet edge detection can be successfully implemented to the true color remote sensing imagery problems. In the meanwhile, the edge and contour of each color component exhibit the independent dynamic ranges which results in better information retrieval.

Conclusions

This research focuses on feature detection and geoinformation retrieval in the remote sensing system where multiscale 2D Gabor wavelet transform is applied. Basic features in remote sensing cover color, edges and contours. More importantly, the interactions and relationships of features can be developed via modeling, so that further information processing could be conducted using powerful high-performance computerized technologies. Even though many edge detection algorithms (e.g., Prewitt, Sobel, Canny) are proposed, it has been depicted that the Gabor transform based approach outperforms those existing methods especially for remote sensing applications. The Gabor filter has the capability of differentiating each remote sensing image with respect to the dominating spatial frequency and orientation. Gabor wavelet transform is able to decompose the remote sensing image into a set of downsized images at multiple scales. Integration of Gabor filters and wavelets has been explored to classify remote sensing images into various components needed by geographical applications. Gabor wavelet transform also helps to differentiate an ideal scale in order to reduce the computation time. The robustness and performance of the proposed approach has been verified by numerical simulations on various aerial color images of lakes, rivers, islands, oceans, and mountains as well as the birdeye views of metropolitan cities. It is shown that true color feature detection and geoinformation retrieval has been effectively accomplished using multiscale 2D Gabor wavelet transform.

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