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Hierarchical Classification of Urban Satellite Imagery Using Gabor Filter and Bayesian Classifier in Intelligent Transportation Application

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ABSTRACT

Intelligent transportation systems have been the most attractive topics among scientific researches. One of the bases of such systems is generating digital maps, and abundantly utilized in GIS, which is why many scientific decisions need this kind of information. In this case, digital characteristics of roads will be derived from image such as coordination of road centerline, the solid objects at the road sides and the bridges. In this paper our aim is to detect roads for providing initial digital maps in remote sensing satellite images from urban areas. For this purpose, firstly, Gabor filter and appropriate structure element along with morphological operation apply to the image as feature extraction method and Bayesian classifier will do the pre-classification step. Afterwards, based on structural profile and according to the urban area satellite image object characteristics, few unknown road parts were detected and classified to freeway along with one or two lane road. Testing mentioned approach signify promising results which demonstrated efficiency of the proposed road extraction algorithm from urban area satellite imagery.

KEYWORDS: remote sensing, Gabor filter, Bayesian Classifier, Structural profile, very-hight resolution satellite imagery.

1. INTRODUCTION

In the recent decade, remote sensing imagery makes the monitoring of the earth's surface and atmosphere possible in various scales. As the technology of the imagery sensors improves, the remote sensing images with higher quality become available. Scientists manage to collect constructive information from the satellite images. In this way, classification of remote sensing images in urban area obtains a lot of information which are useful for emergency application, traffic surveillance, earth survey, map updating and GIS, planning, emergency response and management, and homeland security applications. Thus, automated and semi automated methods for the classification of roads, buildings, and other land cover types in the urban areas attract many research's interests. One of the most important applications of this technique is map updating. In particular, in some regions that their map is not prepared, using of such automatic methods, effectively help civil engineers to make important decisions, immediately. Providing the digital maps, give opportunity to the engineers to evaluate several alternatives for new roads, because these kinds of maps can be imported to navigation instruments such as GPS (Global Positioning System) for finding actual position on the earth. Classification of man-made objects is accomplished using pixel-based or object-based methods. In Pixel-based methods [1, 2] n-dimensional vectors from the gray level data of each part of input image are made afterward, they are compared to a reference vector, trained using a remote sensing image database. Whilst in the object based approaches, groups of pixels instead of each pixel are considered to recognize the image objects. Consequently, neighborhood relationships and shape characteristics are significant for classification of such images.

By increasing the resolution of images, the accuracy of pixel-based methods for classification of multi-spectral remote sensing imagery such as minimum distance from means and maximum likelihood [3, 4] declines. Furthermore, different classes have similar spectral. As a result, classification of such classes encounters error. Meanwhile, Fuzzy based methods for classification provides better solution for such problems, because they attribute fuzzy membership class to pixels. In [5] A fuzzy based classifier was introduced which has shown its superiority over simple ANN classifier. Fusions of fuzzy approaches have been utilized in [6] to improve classification accuracy. In [7], based on spectral similarity of many urban lands cover types and spatial information such as texture and context an accurate classification map from input image has been obtained. Then, a fuzzy classifier has been utilized for the classification of urban area. An object-based algorithm for the

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classification of dense urban areas from multi-spectral IKONOS images is introduced [8] in which a cascade combination of a fuzzy pixel-based classifier and a fuzzy object-based have been exploited. The fuzzy pixel-based classifier has extracted the spectral content of the scene while the spatial context information has been analyzed, fuzzy object-based classifier. Employing support vector machine (SVM) for classification of urban area in satellite images has been presented in [9]. Firstly the hierarchical relationships between the pixels and the adaptive regions to which they are associated at different levels are considered to make the feature vectors. Then, these feature vectors have been fed to SVM classifiers. Segmentation techniques, proposed in [10, 11], have been applied to remote sensing imagery for classification. In [10], some of morphological operations have been utilized for segmentation. In [12] an algorithm, which applied laplacian as feature, has been introduced. First Laplacian of satellite image is obtained. Afterward, it is fed to a special Bayesian classifier for building extraction. Then urban areas, roads and streets are extracted using structural features. In [13] the unsharp masking technique as preprocessing step is applied to improve the local image. Then the building extractor which was mentioned in [12] detected the buildings with an improvement of accuracy. In the proposed approach Gabor filter bank as feature is utilized. Before that some of morphological operations (closing and filling) is applied for the extraction of large buildings .then the buildings are eliminated from original image. Finally, feature based classifier removes the open areas. After that, opening with multi-sized and multi direction structure elements is applied to Gabor filtered image so streets and highways are extracted in favourable sizes. To obtain road centerlines, thinning operation is employed. Then, the contour of each road is traced and smoothed using a Gaussian filter.

The rest of this paper organized as follow. In section 2, a review of Gabor filter as criterion which indicates the variation of image intensity introduced. The techniques for identifying building, streets, highways, shadows and open areas are described in section 3. Experimental results are presented in section 4, followed by conclusion in section 5.

2. METHODOLOGY

2.1 Gabor Filter

2-D Gabor filters are effectively utilized in many computer vision applications. They are one of the most appropriate tools for image analysis approaches such as texture boundary detection, texture image segmentation/ discrimination and texture classification/recognition [14, 15]. Recently for textile flaw detection [18] 2-D Gabor filters have been applied as an efficient step for feature extraction.

In varieties of applications such as texture analysis, classification, segmentation, etc, which distribution of edges gives valuable information, employing edge detection for better classification is necessary. Gabor filter is used to improve desirable frequency components of image. Three ways have been recommended for designing of 2-D Gabor filters: filter banks, tuned matched filters and individual filter-design. For covering the frequency plane the filter-bank approach [15], requires a large set of filters with predetermined parameters. Although such a large bank of filters may aid segmentation, it can dramatically affect the quality of recognition during the classification [19]. Also the individual filter-design approach involves selection of the appropriate filter parameters. The choice of these parameters is crucial for texture processing tasks. For instance, texture boundaries can only be detected if the filter parameters are chosen suitably [20]. In both, tuned matched filters and individual filter-design methods, "high-dimensionality" is reduced.

Figure 1 depicts spatial conception of Gabor filter applied to the urban area remote sensing image. 2D Gabor filter which is an example of wavelet filters, achieve joint localization and resolution in spatial space and frequency domains.

I(x,y) Presents the intensity of input image located in $\mathbf{x^{th}}$ raw and $\mathbf{y^{th}}$ column. Here, the formula of a complex Gabor function in space domain is given:

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

Where **S(x,y)** is a complex sinusoidal, known as the carrier, and $\boldsymbol{\omega_r(x,y)}$ is a 2-D Gaussian-shaped function, known as envelop. The complex sinusoidal is defined as follows,

$$s(x,y) = \exp(j(2\pi(u_0x+v_0y)+P)) \tag{2}$$

Where $(\mathbf{u_0,y_0})$ and P are the spatial frequency and the phase of sinusoidal, correspondingly. We can imagine this sinusoidal as two separate real functions, conveniently allocated in real and imaginary part of a function.

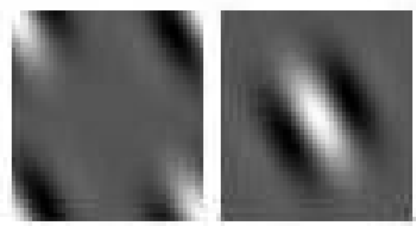

Figure 1. The figure shows Gabor filter

The $\mathbf{u_0,y_0}$ define the spatial frequencies of the sinusoidal in Cartesian coordinates. This spatial frequency can also be expressed in polar coordinates by $\mathbf{F_0}$ as magnitude and $\boldsymbol{\omega_0}$ as direction:

$$F_0=\sqrt{u_0^2+v_0^2}\ ,\quad \omega_0=\tan^{-1}\left(\frac{v_0}{u_0}\right),\quad u_0=F_0\ \cos\omega_0\ ,\quad v_0=F_0\ \sin\omega_0 \qquad (3)$$

The representation of complex sinusoidal is:

$$s(x,y)=\exp(\ j(2\pi F_0(x\ \cos\ \omega_0+y\ \sin\ \omega_0)+P)) \qquad (4)$$

The Gaussian envelop is:

$$\omega_r(x,y)\ =K\ \exp(\ -\pi\left(a^2(x-x_0)_r^2+b^2(y-y_0)_r^2\right)) \qquad (5)$$

As following in equation we have:

$$\begin{aligned} g(x,y) &=K\ \ \exp\left(-\pi\left(a^2(x-x_0)_r^2+b^2(y-y_0)_r^2\right)\right)\exp\left(j(2\pi(u_0x+v_0y)+P)\right) \\ &=K\ \ \exp\left(-\pi\left(a^2(x-x_0)_r^2+b^2(y-y_0)_r^2\right)\right)\ \exp\left(j\left(2\pi F_0\left(x\ \cos\ \omega_0+y\ \sin\ \omega_0\right)+P\right)\right) \end{aligned} \qquad (6)$$

$$I_g(x,y)=I(x,y)*g(x,y) \qquad (7)$$

In this paper we have $K=1,\ a,b=15,\ P=1,\ \ x_0,y_0$ are the half of the height and width of $\mathbf{g}$, in that order. Gabor filter is constructed in image. Using Gabor filter and convolving to the original image, we can present edges in the urban image. Several details are indicated in the image results. Urban remote sensing images, analyzed in this way, are more efficient and more reliable than other high pass filtered images.

2.2 Morphological Operation

Using Morphological operations, the objects can be extracted easily and effortlessly. The precise nature of the expanding or shrinking is determined by a kernel provided by the operator. Morphological operations have been used for extraction of image objects and spatial form of image components modification. We defined an image as an (amplitude) function of two, real (coordinate) variables $\mathbf{I_g(x,y)}$ or two. An alternative definition of an image can be based on the notion that an image consists of a continuous or discrete coordinate set. In a sense, the set corresponds to the points or pixels that belong to the objects in the image.

The common effect of dilation is to take each pixel of intensity in source image and expand it into the shape of the kernel. The contribution of the source pixel to the kernel-shaped region depends on two parameters: the brightness of the source pixels (pixels intensity contribute supplementary) and the values of the kernel pixels (pixels are dark, relative to the centre of the kernel; contribute more to their locations in the kernel-shaped regions than pixels are intense). But morphological operations, opening and closing, are not performed directly. Also, the opening operation can be accomplished by erosion operation followed by dilation operation. The close operation is a dilation followed by erosion. Opening and closing have been used because these operations help to illustrate the structural properties of different objects. By filling operation all of the closed clusters using mentioned morphological operations are filled. Moreover, some techniques have been utilized for elimination of non-road objects.

2.3 Structure Element (SE)

Pattern of the extracted objects was represented in last section; the mentioned method obtains empirical knowledge from components of urban areas remote sensing images and understanding about location and characteristics of urban objects. In this step of our approach, extraction of roads and their size classification and another parts of urban areas components. Here, first we extract the roads from the original image. We initialize the rectangular structure element for searching the roads, and then we slip it along image. Then we resize and rotate it to find roads. $\mathbf{I_{g\theta}(x,y)}$ is road's cluster which is collected in this set.

2.4 Evaluating The Road Centerlines and Bayesian Classifier

Evaluating the road centrelines, referred to as road tracing in literature, is an important step toward generating a digital map. In previous sections was regarding applying Gabor filter in multi-directions along with morphological operation and structure element in order to extract some object in images. It has an essential role for eliciting image's features and it will prepare image for classification. In this approach, the Bayesian classification function applies to classify the roads of urban areas by the feature which represents amount of the edges extracted from Gabor filter, morphological technique, and structure element. The obtained information gathered for classification of road and non-roads. Afterward, A thinning operator is applied to the detected road and for declining abrupt changes of the centreline location, its contour is obtained and is smoothed by applying a Gaussian filter. After obtaining the location of each pixel in the road centreline, we can precisely generate a map in which by clicking in each part of the roads, its precise coordination is clear. Consequently, the digital map can be used for navigation instruments such as GPS.

3. RESULTS AND DISCUSSION

In this section, we demonstrate the application of the proposed common methods to improve intelligent transportation systems. The discussed method applied to very high resolution satellite images from Reykjavik, Iceland. The most important classifications were considered in each case, namely large buildings, houses (small buildings), shadows, roads, and open areas. Each image consists of urban area components including buildings, roads and open areas but we classified it as roads and non-roads classes because of focusing on roads as transportation system. The primary experimental result illustrates a significant improvement in extraction of roads. The SE size in morphological operation filtering is equal to a 3-by-3 square matrix form and the linear shape structure element with various directions by 30 pixels length.

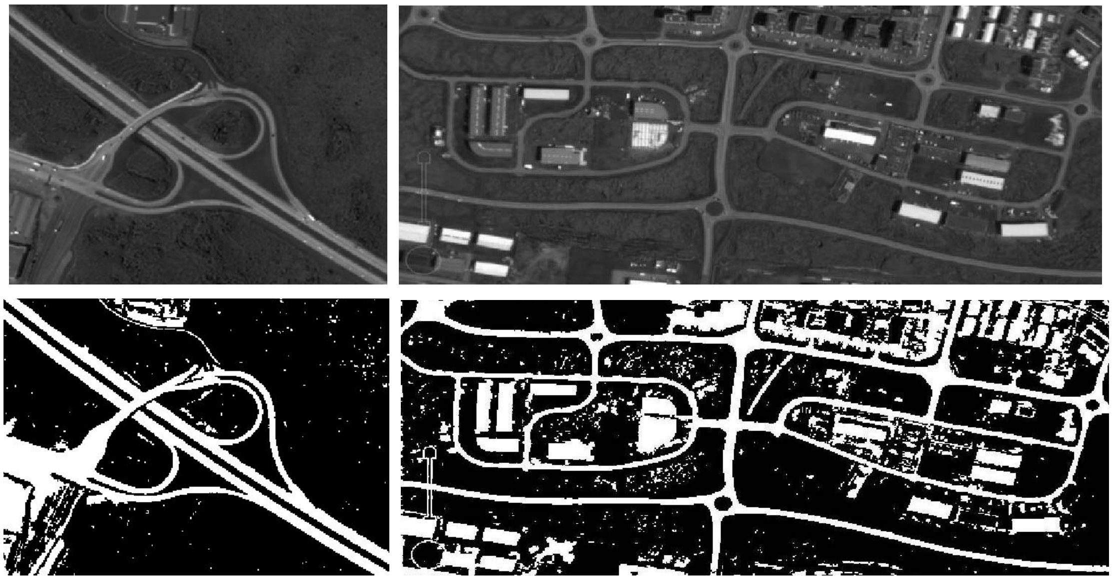

Figure 2. The figure presents some results of mentioned approach before structural profile.

3.1. Pre-classification

The images used to test in the proposed approach have 1024 × 716 pixel. As we know about the results of applying Gabor filter in the input image and the ability of the discrimination; some urban area images are used to benchmark the approach. The methods which haven't being pre-processed, preprocessor like Gabor filter part, do not enhance the image contrast. Thus, the discriminator shows error because some image components have similar level of intensity to the level of background. The Gabor filtering gives us an opportunity to focus in the direction of defining edges. As it's mentioned earlier, we have a trade between sides and time consumption in our algorithm. In fact, if we consider lot of sides to apply Gabor filter, the algorithm will be more time consuming than main and secondary directions. Appropriate levels of discriminated frequency and amount of edges, is obtained by using the training map. It was also considered that, the small buildings have high-frequency components and they have a grained texture on their edges. While building roofs have smooth texture in satellite images.

3.2 Structural Profile

Structural profile method can significantly diminish the rate of false positive results and other errors and the way of using it make this paper novel and interesting. This function operates on objects, roads and highways, with labels attached to them. The haziness in detector responses is resolved by using structural profile instead of morphology functioning and pixels labeling which used in [7, 8, 21]. The reference structure obtained from training map via a mathematical graph. For applying structural profile, the training map has been made which is previously utilized for Bayesian classifier. The training map obtained from our dataset has the properties of being quintessence in urban region. This technique connects urban area objects through structural profile. A neighborhood relation is specified on the set of objects. The importance of implementing algorithm was for obtaining worthwhile structural profile function. It considerable that it does not mean that we are classifying all of the urban image components. We just check the accuracy of components from roads side view. Then, we arrange a set of Graph models from structure profile of urban areas and component shapes as it is required for implementing the profile.

Also, it can solve time consuming drawback of other methods like morphology functioning. Because urban areas images are very large in size and we should organize each note of graph to each pixel. Also the number of notes in graph makes the analysis very lengthy and time consuming. In fact, we have solved this problem by using structures instead of pixels as it reduces the time span for algorithm. As considered earlier, the proposed approach used was based on structural, contextual, and statistical information of urban images. It means that the purposed approach considered in aspect of structural by using morphological operation, and using the contextual information of urban image in a similar manner by using structural profile.

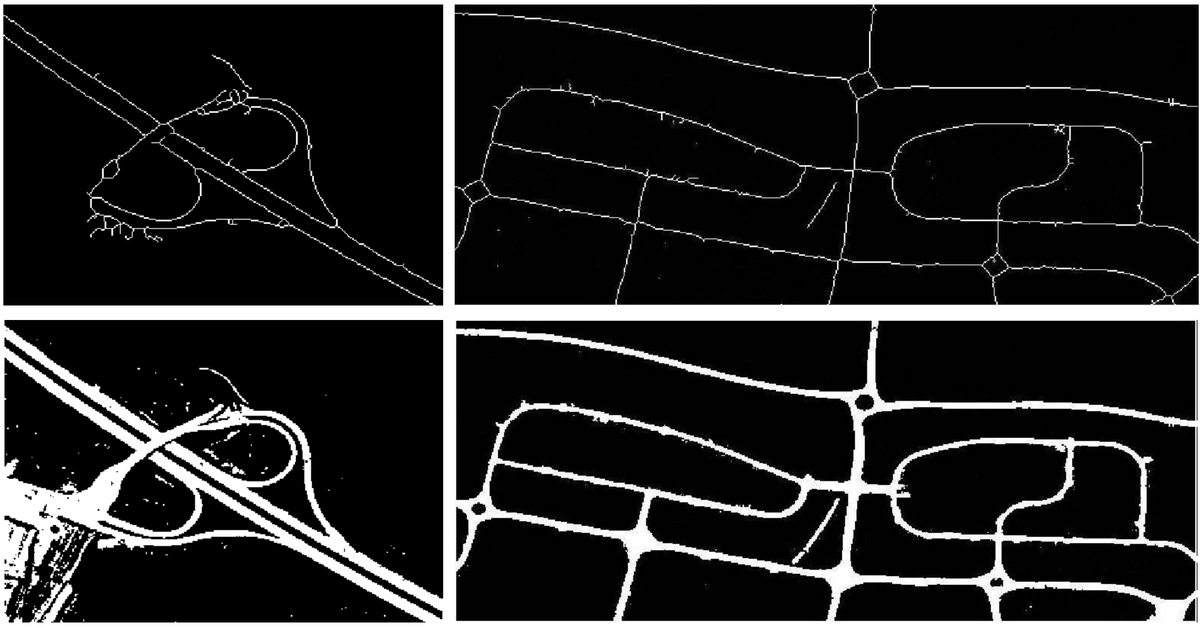

Figure 3. The figure presents some results of mentioned approach after applying structural profile.

Moreover, profile of the structural information of image component helps in making the training map and structural graph model. The figure 3 roughly shows the comparison between mentioned technique and previous results.

4. CONCLUSION

In this paper a new method for extraction of road centerlines in remote sensing images to aid intelligent transportation presented. The mentioned system can generate digital map of roads, and abundantly utilized in GIS. Digital characteristics of roads will be derived from image such as coordination of road centerline, the solid objects in the road sides. The opening with multi-sized and multi direction structure elements is applied to Gabor filtered image. So streets and highways are extracted in favorable sizes. This part developed as a pre-classification step. Afterward, structural profile method and according to the some of the image object characteristics, some of the unknown road parts detected and classified to free-way and one or two lane road. For evaluating road centerlines morphological operation is applied to the extracted roads and highways.

Finally for providing smooth centerlines a Gaussian filter was applied to the contours. As it mentioned before, the novelty of this approach is because of the way of using structural profile. The Results indicated promising results in evaluating road centerlines as an effective step toward generation of digital maps from remote sensed images.

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