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Automatic Extraction of Urban Road Centerlines from High-Resolution Satellite Imagery Using Automatic Thresholding and Morphological Operation Method

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Abstract

The commercial high-resolution imaging satellite with 1 m spatial resolution IKONOS is an important data source of information for urban planning and geographical information system (GIS) applications. In this paper, a morphological method is proposed. The proposed method combines the automatic thresholding and morphological operation techniques to extract the road centerline of the urban environment. This method intends to solve urban road centerline problems, vehicle, vegetation, building etc. Based on this morphological method, an object extractor is designed to extract road networks from highly remote sensing images. Some filters are applied in this experiment such as line reconstruction and region filling techniques to connect the disconnected road segments and remove the small redundant. Finally, the thinning algorithm is used to extract the road centerline. Experiments have been conducted on a high-resolution IKONOS and QuickBird images showing the efficiency of the proposed method.

Keywords

Automatic Thresholding, High-Resolution Imagery, Morphological Operation, Posts Processing, Thinning Algorithm, Urban Road Centerlines Extraction

1. Introduction

The automatic urban road network extraction and spatially up-to-date mapping are very important for various application ranging from updating GIS database for urban transportation mapping and maintenance, E-911, city

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planning and land management, vehicle navigation, to transportation safety, hazards, and disaster management. With the advent of satellite remote sensing images are capable of collecting and providing a huge volume of data to analyze global information, which is quite a difficult task based on conventional mapping techniques, aerial photographs using mostly, which defends on the weather condition and photographic scales. These techniques are time-consuming and costly to fly on the regular basis, especially for urban road centerline updating and change detection in the urban area with rapid construction and destruction. However, a new generation of high-resolution satellite images provides one way by which large area may be mapped correctly and efficiently to minimize the cost and save the time.

Recently, high-resolution commercial imaging satellites have been launched ranging from (0.6 - 4 m), including IKONOS (1 m panchromatic and 4 m multispectral) in 1999 and QuickBird (0.6 m panchromatic and 2.4 m multispectral) in 2001. In the next few years, there are several other satellites which will be launched, including optical imaging satellite such as KOMPSAT-2 (1 m panchromatic and 4 m multispectral) and Orbview 3 (1 m panchromatic, 4 m multispectral) and radar imaging satellite such as RADARSAT-2 (3 m) Canadian satellite and Terra SAR (1 m) European satellite.

The authors [1] [2] presented initial studies which indicated that it is possible to use 1 m resolution satellite imagery to identify, interpret, and extract selected urban objects at 1:2000 scale in all classes of an area (densely populated urban cores, suburban residential areas). In addition, their high temporal resolution (short orbital revisit period, e.g., 1 - 3 days) makes these images ideal source for change detection and hazard assessment. These satellite sensors provide stereo and multispectral information that is useful for automatic road extraction, terrain modeling, and 3D scene analysis.

Automatic urban road network extraction from high remotely sensed data is motivated, in particular, by the rapid demand for accurate and up-to-date mapping application related to urban planning and traffic flow analysis and simulation, road maintenance and/or rehabilitation, estimation of air and noise pollution. Acquiring mapping-quality digital images from space to allow frequent geographical information system database updating is half the battle in urban environmental management. The other half is extracting information from the imagery. Automatic extraction of urban road provides a challenging task for geomatic and mapping engineers. Satellite remote sensing techniques provide efficient information concerned to the road to improve the transportation of urban and suburban areas.

In the last three decades, the application of high-resolution satellite images has been explored in the area of information extraction such as building and road network. Nowadays the high-resolution satellite data have become easily available for commercial purposes and for the researcher. Therefore, it helps to recognize the urban roads, for applications in transportation and computer vision. The high-resolution remotely sensed images are desirable to use an algorithm and to extract urban road easily. Unfortunately, the application of every algorithm varies according to the resolution of the image. In some images, the algorithm contributes excellent result, while in some images the algorithm may fail to extract automatic urban road network. Road segment can be occluded by the nearby objects like the shadow of trees along the road which may disconnect the road segment and will hide some part of the road due to high rise building. However, the spectral values are different and their widths may change. In addition, some junctions of an unknown number of roads may increase the difficulty of urban road extraction. Consequently, advanced methods are required to extract the road network from high-resolution satellite images, *i.e*. IKONOS and QuickBird. Automatic road network extraction from high-resolution satellite images are important aspects due to main three reasons. Firstly, the detection of result can be used in updated map preparation. Secondly, it can be applied in trajectory planning for unmanned aerial vehicles and thirdly, it is important for navigation and computer vision to identify the position of road extraction. Although cartographic and mapping expert can label road pixels from a high-resolution satellite image, but this process is full of errors. Therefore, automatic extraction of road techniques is needed in a high-resolution satellite image in robust manner [3].

In this study automatic approach has been used to detect the road network from highly remotely sensed imagery such as IKONOS and QuickBird. In this proposed methodology initially automatic thresholding is applied on color IKONOS and QuickBird images for segmentation purposes to make it binary image. This method can be employed to multispectral satellite imageries to obtain the desired result for urban road extraction. There are various methods to detect the road network from a given satellite image. The author, [4] [5] developed a method to detect the main roads from satellite images. Primarily they detect the straight lines and homogenous regions. Then, they connect the detected primitives. Unfortunately, their method cannot detect urban roads correctly and occluded road segments. Discontinuous road segments were linked using perceptual organization rules by [6].

The authors, [7] [8] presented an excellent survey on road detection in aerial and satellite images. Satellite images are attractive means to collect data for road an excellent extraction particularly from IKONOS and QuickBird. For the identification of roads related problems, the spectral and spatial resolutions are important characteristics to be considered. This technique requires excellent spatial, spectral, and temporal resolution to demarcate specific urban and suburban attributes using space-borne technology. [9] presented a study for the interpretation and detection of satellite images to recognize artifacts and natural objects such as trees, shrubs, rocks, street, bridges, and open field. They pointed out that for the detection of paved roads, 2 m spatial resolution images is required. [10] carried out that a spatial resolution ranging from 0.25 - 0.5 would be necessary to detect urban road.

The author in [11] presented an automatic method for extracting of the road based on the ISODATA segmentation and shadow detection from large-scale aerial images. Paper [8] has used active contour model also called as Snake algorithm to extract urban features from remotely sensed imagery. The [12] proposed an approach to extract building from high-resolution satellite imagery using structural, contextual and spectral information. Paper [13] presents a novel methodology for fully automated road centerline extraction that exploits the spectral content from high-resolution multi-spectral images. The researchers [2] [6] [14] [15] have used the approach to mathematical morphology for extracting urban features from remotely sensed data. The main purpose of this paper is to present a novel method that combines the automatic thresholding and morphological operation techniques to extract the centerline of the road network in urban environments. Based on the automatic thresholding, a morphological operation method is proposed. As an application, the proposed morphological operation method is used to extract centerline of urban road network from high-resolution remote sensing images such as IKONOS and QuickBird images.

2. Methodology

In this paper, a novel method is presented to detect the urban road network in high-resolution satellite images *i.e.* IKONOS and QuickBird. The proposed method is based on four main steps. Firstly, automatic thresholding is employed to segment roads from the color image to binary. This technique is shown similar concept used by [16] [17] presented global thresholding to segment roads from cropped image. Secondly, the morphological operation procedure is applied in the segmented inverted binary image, such as dilation, erosion, opening, and closing techniques are performed to highlight the road network and remove the undesired objects [18]. The third, steps are to use some filters, for example, reconstruction of lines segment to connect road network and link roads segment to each other and apply region filling method to remove the small redundant in the binary image. Finally, post-processing procedures are used, such as thinning algorithm develop by [19] to extract the urban centerline of the road. **Figure 1** shows a complete procedure of urban road network stepwise.

2.1. Extraction of Urban Road Networks

Extraction of the urban road network is an important process in remote sensing satellite field. The first step of the proposed method is the segmentation approaches are used to extract the roads from the high-resolution images such, as IKONOS and QuickBird. To do this experimentally, three approaches automatic thresholding, morphological operations and finally, post-processing method are employed on satellite images. In the past literature review, the researcher has used Canny edge detector and Sobel techniques for detection of edges, however, the result is not according to the desire results and have some limitation to road extraction. The excellent result is obtained using automatic thresholding approaches and afterward morphological operations, post-processing techniques are applied to extract the centerline of urban roads. Before applying the segmentation approach, a region of interest is selected from the testing IKONOS and QuickBird images, where, urban roads are more prominent. The region of interest is a part of testing images, which could be sub-image of rectangular shape with the size of 2.95×3.28. The intended algorithms provide excellent result in the whole experiments [20].

2.2. Automatic Thresholding Approach Based on Urban Road Detection

This algorithm is based on automatic thresholding which is used to segment the urban roads networks from high-resolution satellite images such as IKONOS and QuickBird. The experimental result of automatic thresholding is illustrated in **Figure 2(a1)** and **Figure 3(b1)**. In the resultant binary image, the roads are assigned white color and background is black in color. The intensity value of the white color pixel is highest then the background. The road network is perfectly detected in both color testing images, however, some misclassification is

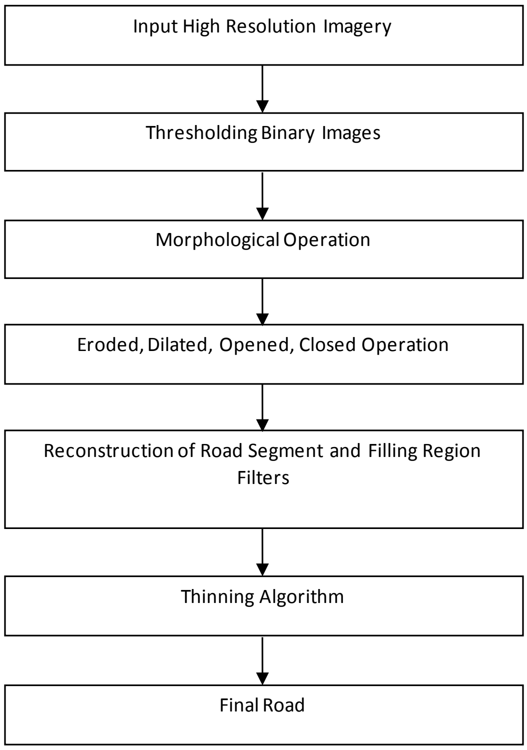


Figure 1. Flowchart for road network extraction.

(a) Testing image (a1) Threshold image (a2) Inverted image

Figure 2. QuickBird result by automatic thresholding.

also reported in the resultant binary images. This misclassification is due to the shadow of trees, buildings and vehicles on the road which have similar spectral color with roads. In order to extract the desired result, the output binary images are converted into inverted images sees **Figure 2(a2)** and **Figure 3(b2)**. In this case, the road network is represented in black color to assumed highest intensity pixel value, whilst, the background is the white color with minimum intensity values, with some similar spectral objects is also reported.

2.3. Urban Roads Extraction Using Morphological Operation Approach

In order to figure out the misclassification objects and remove the redundant features from the images, some morphological operation is used in the segmented threshold inverted binary images such as eroded, dilated, opened and closed techniques sees **Figure 4** and **Figure 5**. During morphological opened procedure **Figure 4(a3)** is a QuickBird image are not properly classified the road network and a lot of redundant objects is detected

(b) Testing image (b1) Threshold image (b2) Inverted image

Figure 3. IKONOS result by automatic thresholding.

(a3) Opened image (a4) Closed image

Figure 4. QuickBird result by morphological operation.

(b3) Eroded image (b4) Dilated image

Figure 5. IKONOS result by morphological operation.

which is not capable of extracting the roads network correctly, While in the case of closed operation excellently detect the roads network with small undesired features. This is due to the open grassy field, building material and car which have similar spectral features with roads. In **Figure 5(b3)** in IKONOS image the road network is detected perfectly with a small spur which is not our demand, whilst, the dilated binary image detected roads networks correctly with some non-linear objects and disconnection of roads segments can be observed in **Figure 5(b4)**, this disconnection of road segment is due to the shadow of trees along the roadside and car on the road may occlude the road network. Morphological operations are based on mathematical morphology, which used for elimination and classifies part of the image based on algebraic non-linear operators. This complete process is employed on the segmented inverted binary image see **Figure 2(a2)** and **Figure 3(b2)**. To reduce the effect of detection of the shadow of trees, car on road and remove nonlinear features some filter are used in the experiment such as roads segment reconstruction to link the road segment which is occluded due to trees shadow and region filling techniques are applied to eliminate the undesired feature having similar spectral objects with roads.

2.4. Post-Processing Procedures

The post-processing procedures are a close connection with filtering, for example, lines or segments reconstruction, region filling and thinning algorithm of roads centerlines extraction.

The scene of the satellite remote sensing images are used in this experiment are complex, the extracted objects are corrupted by other objects. For example, the shape of the road can be affected by vehicles, shadow of trees and buildings on the roads. In addition, some non-road objects having similar color features with road can also are misclassified is the roads see **Figure 6(a4)**, **Figure 6(b4)**. It can be observed some disconnection of road segments in the experimental result. In order to finish this problem of misclassification, shadow of trees and other similar spectral object to extract roads network correctly, some filtering procedure is necessary to end this issues. For this purposes segment, reconstruction and region filling techniques are used to eliminate the effect brought by cars, shadow of trees and building shown in **Figure 7(a4)**, **Figure 7(b4)**, region filling is used to clear off the misclassified non-road features having non-linear shapes.

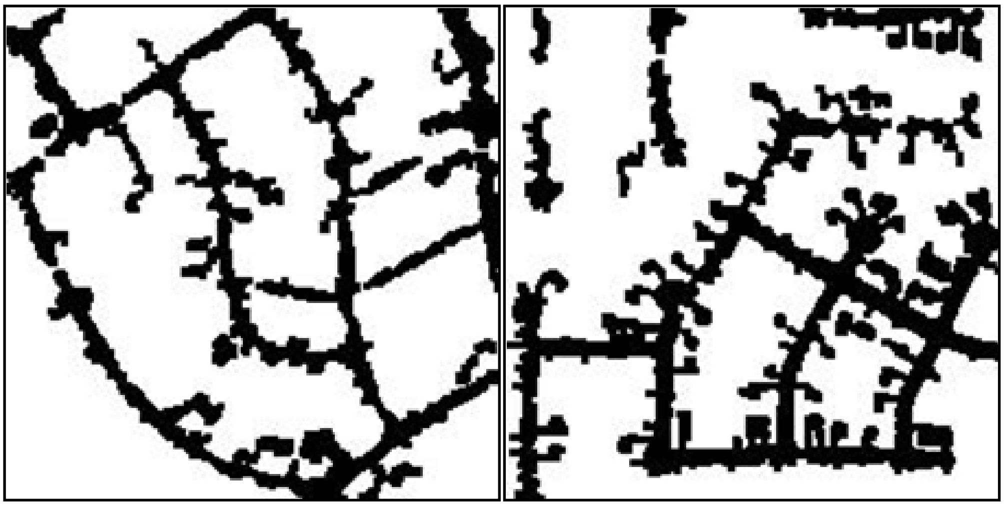
Finally, the thinning algorithm procedure is carried out by [19] to extract the centerline of the road. The road centerlines are accurately detected illustrated in **Figure 8**.

3. Results and Discussion

Binary segmentation methods have been used to extract the urban road from the high-resolution satellite image. To extracts the efficient results in the image, automatic thresholding approach is applied on the color IKONOS and QuickBird images to convert them to binary images, road and background segments. Several problems are examined to compute the appropriate threshold value, for example, the different pavement material used on the

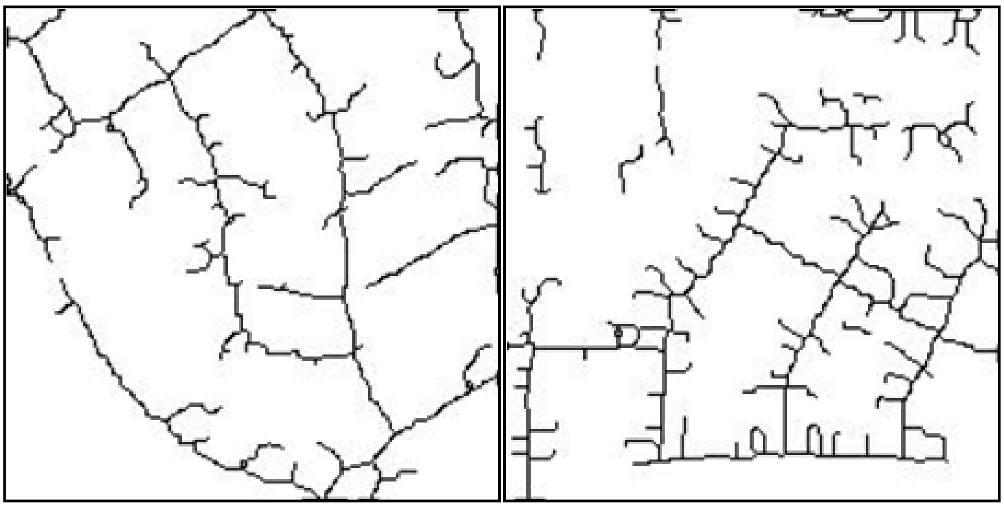
(a4) (b4)

Figure 6. Binary images. (a) QuickBird; (b) IKONOS.



(a4) (b4)

Figure 7. Filterbinary images. (a) QuickBird; (b) IKONOS.



(a4) (b4)

Figure 8. Thinning road centerline images. (a) QuickBird; (b) IKONOS.

roads and the presence of objects such as trees, vehicles, building etc. Then automatic threshold segmented binary image is converted to an inverted binary image which provides a base for further processing in which the roads is represented is black in color with highest intensity value 1, while non-road features are presented in white color with low intensity value is 0. After that morphological operation procedure is employed in the inverted binary image to detect the roads network and remove the small undesired objects and minimize the detection of non-road pixels. Such as opened, closed, erode and dilated operations are applied see **Figure 4** and **Figure 5**. In **Figure 4(a4)** close operation QuickBird image is much better result than open operation image (a3). While, on the other hand in **Figure 5**. IKONOS dilate operation image (b4) have excellent result than (b3). In order, to process the experiments for further process QuickBird closed image (a4) and IKONOS dilated image (b4) is selected to continue the experiment more convincing. A spatial filter is developed such as road segment reconstruction, to link the road segment with each other which is disconnected in **Figure 6**. While region filling techniques are applied to remove the undesired features such as small nonlinear features which are considered to be non-road see results **Figure 7(a4)**, **Figure 7(b4)**. The experimental result shows the efficiency of our proposed method as compared with the result of [17] [21] [22]. MATLABR2014a software is used for the implementation of this proposed procedure.

Finally, the thinning algorithm is carried out to extract the centerline of the road, this thinning algorithm used by [19] illustrated practical result in **Figure 8**. In which the QuickBird (a4) is better result than IKONOS (b4) is due to the complexity of the scene.

4. Conclusions

The proposed method of combining automatic thresholding and morphological operations is used to extract the road network from high-resolution satellite imagery. The significance of this approach is to introduce combining techniques of automatic thresholding followed by the morphological operation are implemented. Extraction of road segmentation has been performed with the help of automatic thresholding, which classified the color image to binary images such as road and non-road objects. The intensity pixel value of road is higher than the background. In order to extract the desired result, the segmented binary image is converting to invert the image, in which the road is shown in black color and background with white color. Then, by employed morphological operation on the segmented image, the proposed method is tested on high-resolution satellite imagery of the urban area. The experimental result points out potential use of proposed procedure in extracting the road network from high-resolution satellite images in an efficient way.

In some part of the images, small area of barren land, vegetation covered area, open grassy fields and buildings area is classified as roads. Filtering techniques are used to remove the unwanted features such as region filling techniques. Finally, post-processing procedure is employed for instances thinning algorithm by [19] to extract the urban road centerline correctly and analyzed with the result of [13]. In future to cope and solve the problem of extraction of non-road segments in an urban area to improve this automate techniques, some soft computing techniques are required.

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