J Indian Soc Remote Sens (September 2013) 41(3):631–640
DOI 10.1007/s12524-012-0241-4

RESEARCH ARTICLE

ISRS

Automatic Road Extraction from High Resolution Satellite Image using Adaptive Global Thresholding and Morphological Operations

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Received: 15 November 2011 / Accepted: 8 October 2012 / Published online: 21 November 2012

Abstract Road network extraction from high resolution satellite images is one of the most important aspects. In the present paper, research experimentation is carried out in order to extract the roads from the high resolution satellite image using image segmentation methods. The segmentation technique is implemented using adaptive global thresholding and morphological operations. Global thresholding segments the image to fix the boundaries. To compute the appropriate threshold values several problems are also analyzed, for instance, the illumination conditions, the different type of pavement material, the presence of objects such as vegetation, vehicles, buildings etc. Image segmentation is performed using morphological approach implemented through dilation of similar boundaries and erosion of dissimilar and irrelevant boundaries decided on the basis of pixel characteristics. The roads are clearly identifiable in the final processed image, which is obtained by superimposing the segmented image over the original enhanced image. The experimental results proved that proposed approach can be used in reliable way for automatic detection of roads from high resolution satellite image. The results can be used in automated map preparation, detection of network in trajectory planning for unmanned aerial vehicles. It also has wide applications in navigation, computer vision as a predictor-corrector algorithm for estimating the road position to simulate dynamic process of road extraction. Although an expert can label road pixels from a given satellite image but this operation is prone to errors. Therefore, an automated system is required to detect the road network in a high resolution satellite image in a robust manner.

Keywords Road extraction · Adaptive global thresholding · Morphological operations · Average intensity

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Introduction

Satellite remote sensing images are capable to collect large volume of data to analyze global information, which is quite difficult to collect from traditional methods. Some important aspects of using satellite image are the capabilities to make available large volume of information, acquire information at difficult-to-reach regions, to monitor areas and events non-intrusively. Satellite remote sensing techniques are quite efficient to make available the information related to roads to improve the transportation of suburban and urban areas. The main purpose of this paper is to explore the capabilities of high resolution satellite images for road extraction.

In the last decade, the use of satellite image has been explored in the area of information extraction. Now a days the high resolution satellite data has become more readily available. Therefore, it helps to identify the roads, for applications in navigation, computer vision and transportation. The high resolution satellite images are suitable for applying computer vision algorithms to extract the road network. Unfortunately, well-known computer vision algorithms are not suitable alone for automatically extracting the road network from a given image due to several reasons. Road segments can be occluded by other nearby objects like buildings and trees. They may also have different spectral values and their widths may change. Moreover, junctions of unknown number of roads and roundabouts may increase the difficulty of the extraction. Therefore, advanced methods are needed to extract the road network from high resolution satellite images.

Road network extraction from high resolution satellite images is one of the most important aspects for three main reasons. First, the detection of results can be used in automated map preparation. Secondly, the detection of network can be used in trajectory planning for unmanned aerial vehicles and thirdly, a wide application in navigation and computer vision as a predictor-corrector algorithm for estimating the road position to simulate dynamic process of road extraction. Although an expert can label road pixels from a high resolution satellite image but this operation is prone to errors. Therefore, an automated system is required to detect the road network in a high resolution satellite image in a robust manner (Sirmacek and Unsalan 2010).

In the present study, a fully automated approach has been used to detect the road network from the high resolution satellite imagery. In the proposed methodology, initially global thresholding is applied for segmentation of satellite imagery. Thereafter, morphological operations are applied to extract road network from the satellite imagery. This approach can be applied to different satellite imageries to obtain the desired results for road extraction. There are several methods to detect the road network from a given satellite or aerial image.

A method was developed to detect main roads from satellite images by Yang and Wang (2007). First, they detected road primitives such as straight lines and homogenous regions. Then, they linked detected primitives. Unfortunately, their method cannot detect urban roads and occluded road segments. Discontinuous road segments were linked using perceptual organization rules by Ma et al. (2007). Parallel edges are detected in panchromatic ETM (Enhanced Thematic Mapper) images to locate road segments. Excellent surveys were provided on road detection in aerial and satellite images by Baumgartner et al. (1997) and Unsalan and Boyer (2005).

Satellite systems are quite attractive way to collect data for road extraction. It also depends upon availability of high resolution satellite imagery. For road extraction applications, and in particular for identification of roads related issues, the spectral resolution and the spatial resolution are two very important aspects to be considered. This technique requires good spatial, spectral, and temporal resolution to distinguish specific urban and suburban attributes using space-borne technology. Specifically, this report states that for road extraction application (count studies, congestion, and velocity studies) a spatial resolution of the order of 0.25–1 m and panchromatic visible spectral resolution are necessary (Jensen and Cowen 1999; Coulter et al. 1999; McFarland 1999; Hung 2002).

Kim et al. (2000) carried out a study for the interpretation and detection capabilities for satellite images for the spatial resolution requirements to distinguish natural and man-made objects such as trees, shrubs, rocks, street, bridges, etc. They reported that for the detection of paved roads, at least a 2 m spatial resolution image is necessary. A spatial resolution on the order of 0.25–0.5 m would be needed to be able to detect road networks (Coulter et al. 1999).

Methodology

In this study, a novel method is proposed to detect the road network in high resolution satellite image. This proposed method is based on three main steps. Initially, adaptive global thresholding is applied to segment roads from the cropped image (Goodman 1997). Thereafter, a road network is extracted on removing small non-road segments by using morphological operations (Li et al. 2005). A spatial road matrix is generated with the help of extracted road networks and its similar pixel intensity values area. This road matrix indicates the possible locations of the non-road segment and finally, a road tracking algorithm is applied on the road matrix to extract only the road networks followed by some morphological operations again. Figure 1 shows a complete framework for extraction of road networks.

Extraction of Road Networks

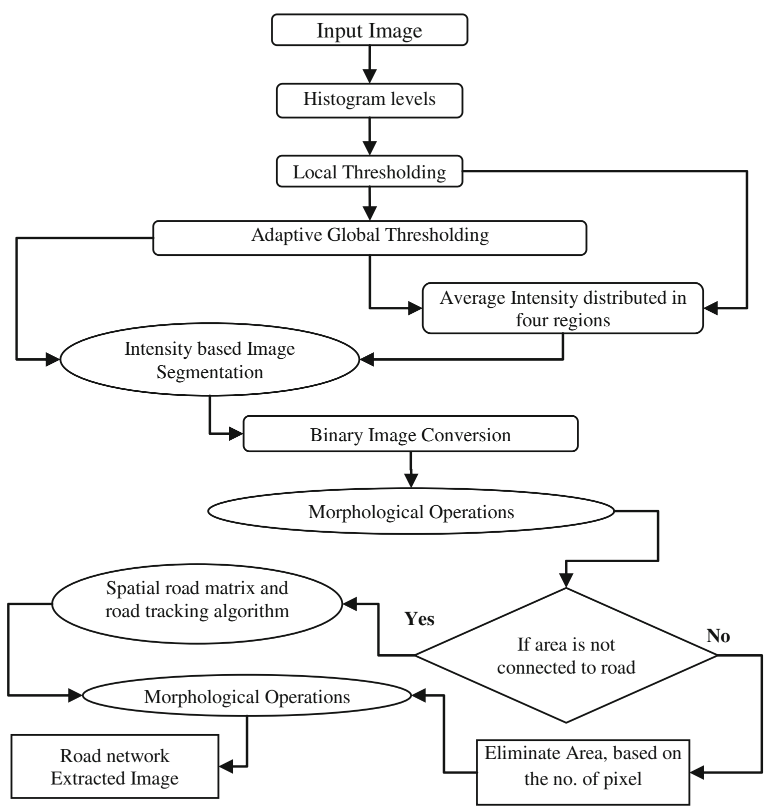
First of all, segmentation techniques are used to extract the roads from the image. To do this, two approaches global thresholding and morphological operations are applied on satellite image. In the literature, researchers have used Canny and Sobel methods for edge detection, but the results were not upto the merit. The better results are obtained using thresholding techniques and subsequently morphological operations. Before applying the segmentation technique, the user is to specify a region of interest, from the original image. The region of interest is a part of image, which could be subimage of rectangular shape. This proposed algorithm helps to provide better results in the regions of interest instead of the whole image.

To compute the appropriate threshold values several problems have to be analyzed, e.g., the illumination conditions, different type of pavement material, presence of objects such as trees, grasslands, lake, vehicles, buildings, etc. To identify most of the possible problems, a high resolution satellite image is studied and analyzed. This test subimage presented various conditions under which the performance of the proposed algorithm is evaluated. In the next section the proposed algorithm is described, and the results are discussed with the help of satellite image.

The Algorithm: Adaptive Global Thresholding Based Road Detection

This algorithm is based on global thresholding, which is used to segment the road networks from the satellite image. Figure 2a shows a typical road network. To obtain the desired results, the histogram of the image containing roads is analyzed and divided in four main regions, as shown in Fig. 2b. Region I starts from the lowest intensity values to midway of Average Intensity (AvIn).

Fig. 1 Framework for Extraction of road networks



AvIn is the arithmetic mean computed using all the pixel values in the subimage.

For most of the cases, the intensity values on this region covers dark objects of the image such as dark vehicles, shadows, lake, muddy ponds, etc. Region II covers intensities that go from approximately midway of the AvIn to AvIn, and typically covers dark gray shade objects like trees, grasslands etc. Region III goes from AvIn, to midway of highest intensities and covers bright gray objects such as asphalt concrete road, lane markers, etc. Region IV goes approximately from midway of highest intensity to highest intensity and generally covers bright objects like concrete cement road, bright vehicles, road dividers etc. This approach assists in handling situations in which single value thresholding will not work, since the threshold for each pixel depends on its location within a satellite image. Therefore, this technique is called adaptive and said approach is called as adaptive global thresholding.

Computing the Threshold (T) for Segmentation of Roads and Objects

After cropping the region of interest from satellite image containing roads, analysis is carried out for the range of intensities for most of the roads including values that are less than the AvIn of the image being observed. Now, the AvIn value of selected intensity range for roads from each row of cropped image (CI)=g (x, y) is calculated to create a row vector (RV). CI is a matrix, whose each element corresponds to the intensity value of the image under the study area. RV has the AvIn value of the corresponding row's intensity of CI. Then, the threshold value T is chosen as the minimum value of RV.

The following steps of proposed threshold evaluation algorithm for segmentation is given to calculate RV (Row Vector) by using CI (Cropped Image):

RV: for each row i in CI
RV[i] = average_intensity [CI, i]
T_{min} is calculated using RV:
    T_{min} = minimum [RV]
    T_{min} is used to convert the test image CI to binary image BI. A pixel at any position (x y),
    if (x y) < T_{min},
        then this pixel is considered as highway (black = 0)
    else
        it is turned white = 1.
The binary image, BI, obtained by T_{min} is defined as:

```
[r c p] = size [ BI ];
RV = mean [ BI ];
T = minimum [ RV ];
for i = 1: r,
    for j = 1: c,
        if I [ i,j ] < T
            BI[ i,j ] = 0;
            end
        else
            BI[ i,j ] = 255;
            end
    end
end
```

By using this proposed method, the calculated threshold value T_{min}=92.2941 is used for the test image as shown in Fig. 3b, c shows the resulted binary image BI.

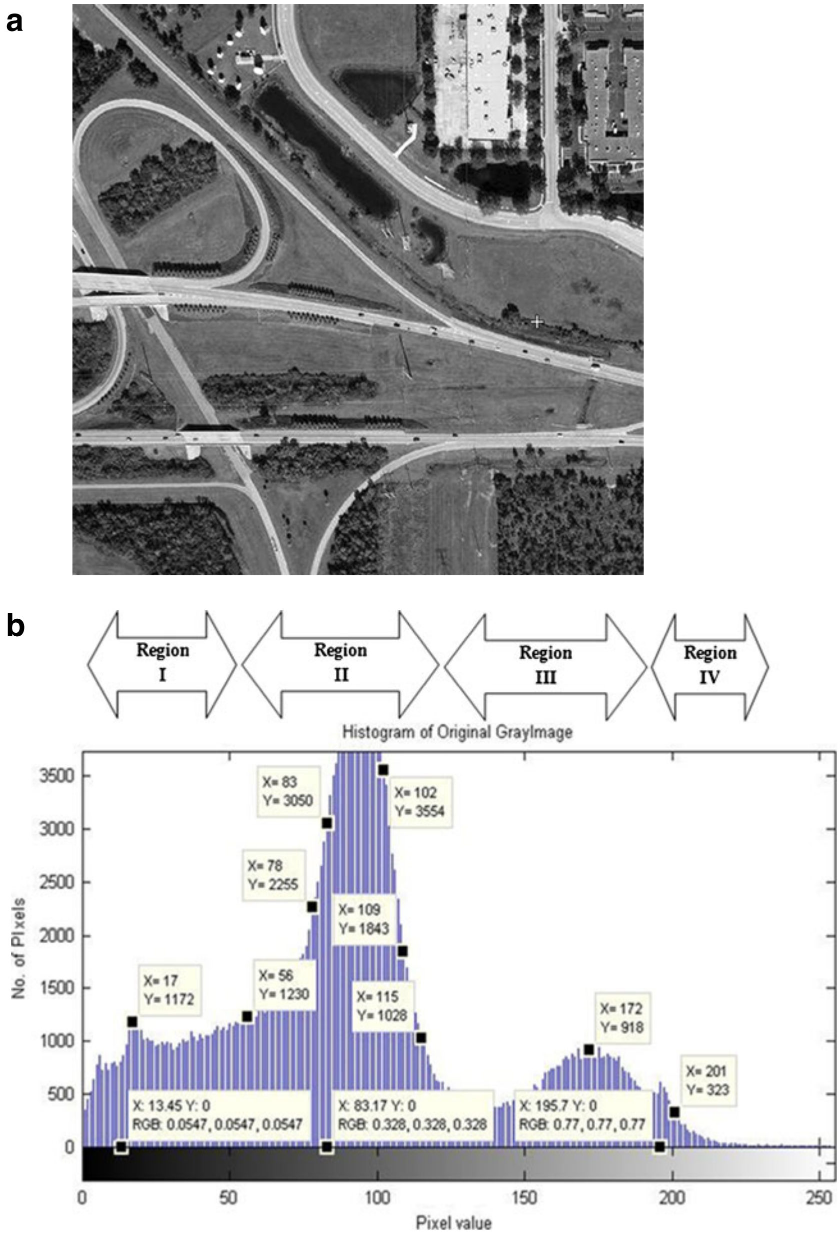


Fig. 2 **a** High resolution satellite image of suburban area **b** Histogram of the image in Fig. 2a

Road Segment Extraction Using Morphological Operations (MO)

As can be seen in Fig. 3c, most road segment boundaries are extracted. Unfortunately, there are some missing road boundary pixels. Besides, there are also boundary pixels from nearby buildings and other objects. Up to this point, adaptive global thresholding method is applied to detect the road network. Next, morphological operations (MO) are used to remove small objects like vehicles and trees. After applying this MO, final image is obtained. Later the intensity image is fused with the final image to detect the road network with a value '0' in binary image.

Morphological operations are based on mathematical morphology, which stands for removing separate part of image with the help of algebraic non-linear operators. This complete processing is applied on segmented image (resulted image after applying adaptive global thresholding). Since any pixel less than T is made as 0 to detect the roads, there are possibilities of detecting dark vehicles, shadows, and trees, which have intensity

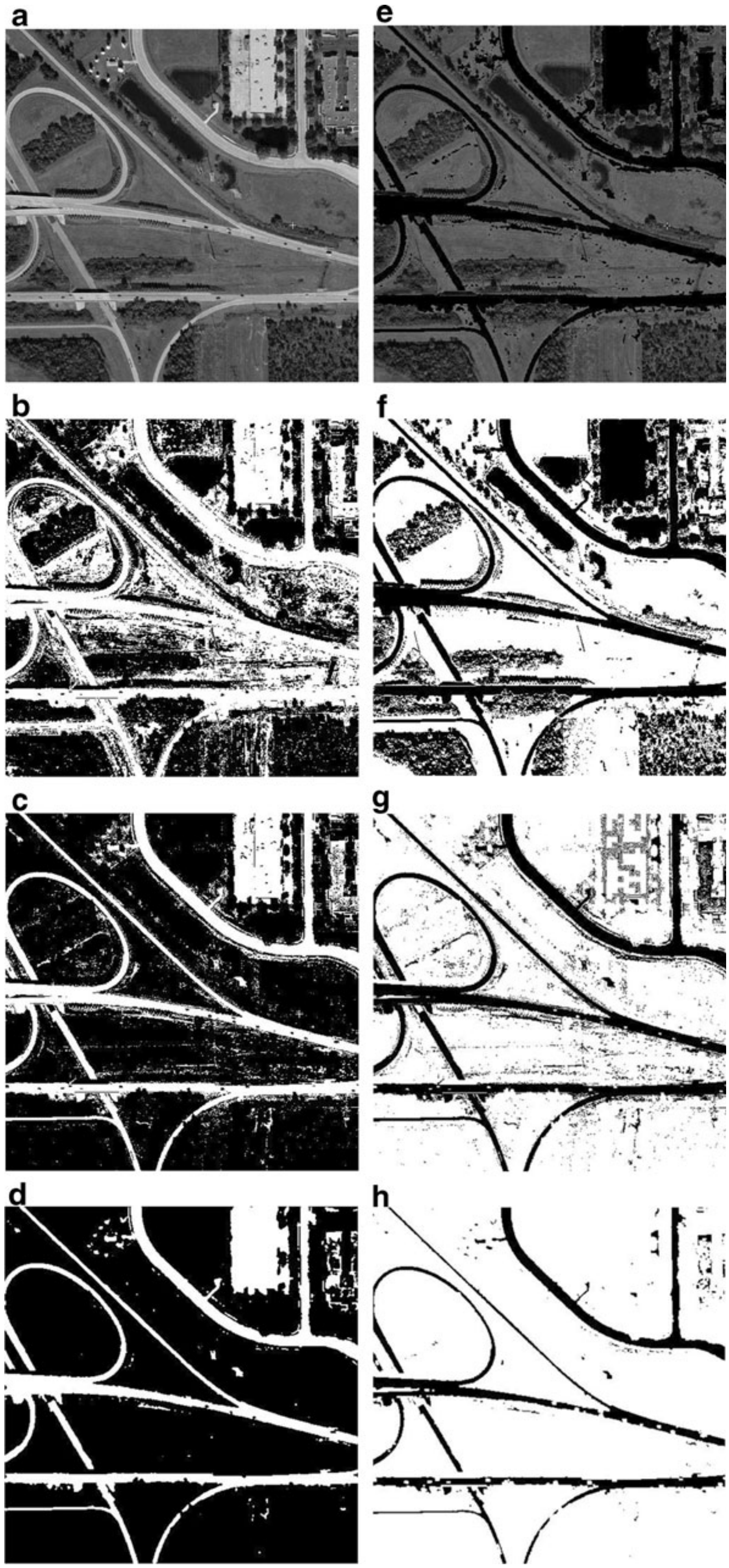


Fig. 3 **a** Original Image of roads **b** Image obtained after applying local thresholding the image in Fig. 3a. **c** Binary image (BI) obtained after applying adaptive global thresholding the image in Fig. 3b. **d** Binary image (BI) obtained after using Morphological operations in Fig. 3c. **e** Intensity image showing roads as pixel value ‘0’. **f** Binary image (BI) obtained from Fig. 3e. **g** Image showing roads, after applying a road tracking algorithm on the road matrix in Fig. 3f. **h** Final Image showing only roads, after applying Morphological Operations in Fig. 3g

values less than T also. In Fig. 3c, it can be observed that roads are dark in color. It can also be observed that there are some isolated black pixels that correspond to dark vehicles, shadows and trees. To minimize the detection of shadows, dark vehicles and trees, four morphological operations as Clean, Majority, Fill and Holes are applied to the binary image BI.

As a result of these four morphological operations, most of the isolated dark pixels would be eliminated. In a particular case, where large areas are covered by trees and vegetation (with intensity values in the range of roads), the possibilities of their being eliminated are minimal. This is due to the fact that these large areas are not isolated set of pixels and the morphological operations, which are restricted to a 3-by-3 block of pixels, would not eliminate them. If the size of the block is increased, there are possibilities of missing the roads. Figure 3d shows the binary image BI obtained after applying the morphological operations.

From binary image BI (Fig. 3d) it is observed that most of the isolated pixels are eliminated. This proposed method extracts the road segments with the help of intensity values of image, which are quite similar with pixel values of road segment in cropped image. This process is implemented in two intricate steps to retrieve the road networks. Initially, a segmented image is found with the help of AvIn values of image in an iterative manner. Thereafter morphological operations are used to remove non-road segments and detect missing road segments after segmentation. This process succeeds with an accurate range of intensity values to extract possible road network segment. Hence, initially a finite range of road segments is required from an exact range of pixel intensity values. This process is improved by applying adaptive global thresholding approach, which splits the histogram of image in four regions. These regions are procured with the help of pixel intensity values.

Obtaining Intensity Image of Roads

To obtain the final intensity image (Fin_Img) showing only roads, pixels with value 0 in BI are considered. If a pixel has value 0 in BI, then the intensity of the corresponding pixel in the original test image CI is copied to Fin_Img. In this way, only the detected roads will be copied from Img to Fin_Img using BI. Figure 3e shows the final image obtained by the algorithm for detection of roads.

The Fin_Img is obtained from BI (Binary Image) and T (calculated Threshold) as given below in proposed algorithm:

```
[row column page] = size [BI];
for i = 1:row,
        for j = 1:column,
                if BI [i,j ] == 0
                        Fin_Img [i,j] = Img [i,j];
                else
                        Fin_Img [i,j] = 0;
                end
        end
end
```

Road Tracking Algorithm on the Road Matrix to Extract only Road Networks

The proposed method is quite useful to remove non-road area, which is having similar pixel intensity values as road network. It shows the novelty in this method. This novel method is applied on the converted binary image (Fig. 3f), which is the resulted intensity image (Fig. 3e). It uses the number of pixels lying in continuous and non-continuous segments with limited width as the road network segment. This proposed method is explained in detail with resulted road extracted image (Fig. 3h) in the next section.

Results and Discussion

Segmentation techniques have been used to extract the road network from the satellite image. To obtain the desired results in the image, the histogram is analyzed for extraction of roads. To compute the appropriate threshold values several problems are analyzed, for instance, the illumination conditions, different type of pavement material, presence of objects such as vegetation, vehicles, buildings, etc. From the analysis, the histogram is divided in four main regions using adaptive global thresholding. This adaptive global thresholding is used to extract the road segments followed by segmentation. MATLAB programming is used for the implementation of this proposed methodology. Some isolated black pixels are obtained that correspond to dark vehicles, shadows, and trees. The proposed method is used to minimize the detection of aforesaid pixels by applying some morphological operations.

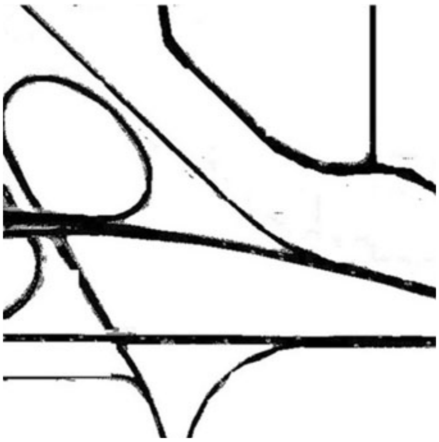


Fig. 4 segmented ground truth road network

A spatial road matrix is generated with the help of extracted road networks and its similar pixel intensity values area. This road matrix indicates the possible locations of the non-road segments by calculating unequal width of area which has similar intensity pixels values as the road segment. The width of area depends on the occurrence of no. of pixels in row and column vector. If it is not connected with a regular pattern of similar width of area, consequently it can be easily identified as non-road segment. If connected, it is identified as road segment with unequal width of area. The spatial road matrix and road tracking algorithm are processed in an iterative manner to detect non-road area. Thereafter, a pixel value is assigned as '255' for detection of non-road area, which is shown in Fig. 3g.

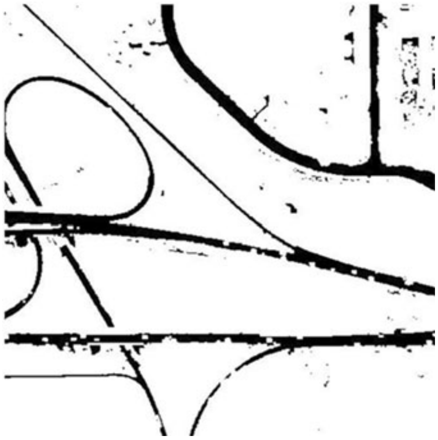


Fig. 5 segmented proposed hybrid method road extraction

Table 1 Quality assessment parameters for road network extraction

Completeness	Correctness	Sensitivity	Specificity	Jaccard index	Dice coefficient
95.32	96.52	95.32	96.56	92.15	95.92

Finally, the proposed hybrid method is applied with morphological operations on resulted image (Fig. 3g), to extract only the road networks as shown in Fig. 3h. Figure 3h shows the accurate road network with the help of proposed hybrid method. The manually delineated road region drawn by an expert is taken as the ground truth in Fig. 4 and compared with the results of proposed road extraction hybrid method in Fig. 5. The performance of the proposed road extraction technique is evaluated using six quantitative parameters like sensitivity, specificity, completeness, correctness, Jaccard index, Dice coefficient. These parameters are used to evaluate the performance of the road detection from the high resolution satellite image. Sensitivity means percentage of road pixels properly included in segmentation results out of all the pixels. Specificity means percentage of road pixels properly excluded from the segmentation results out of all the pixels outside of ground truth road.

These parameters are defined as follows:

$$\%\ \text{Sensitivity} = \left(\frac{\text{TP}}{\text{TP} + \text{FN}}\right) \times 100 \tag{1}$$

$$\%\ \text{Specificity} = \left(\frac{\text{TP}}{\text{TN} + \text{FP}}\right) \times 100 \tag{2}$$

TP or true positive means a pixel appearing in both manually segmented road area and road area detected by proposed hybrid method. TN or true negative means a pixel absent in both manually segmented road area and road area detected by proposed hybrid method. FP or false positive means a pixel absent in manually segmented road area but appearing in road area detected by region-growing method. FN or false negative means a pixel appearing in manually segmented road area but absent from road area detected by proposed hybrid method (Metz 1978).

Table 2 Quality measurement parameters for road network extraction

Accuracy	V_{SGT}	V_{AGTMO}
95.94	507.71	501.40

Mathematical analysis includes the completeness and correctness to evaluate the accuracy of the extracted road network (Heipke et al. 1997). Completeness is defined as the percentage of the reference data which is detected during road extraction

$$\text{Completeness} = \frac{\text{length of matched reference}}{\text{length of reference}} = \frac{TP}{TP + FN} \quad (3)$$

Correctness represents the percentage of the extracted road data which is correct

$$\text{Correctness} = \frac{\text{length of matched extraction}}{\text{length of extraction}} = \frac{TP}{TP + FP} \quad (4)$$

Jaccard index is a statistical measure of similarity between sample sets. For the two sets, it is defined as the cardinality of their intersection divided by the cardinality of the union. Like the Jaccard similarity index, the Dice coefficient also measures the set agreement. It gives twice the weight to agreements. For the two sets, it is defined as the cardinality of their intersection divided by the cardinality of the addition. A value of 0 indicates no overlap and 1 indicates the perfect agreement. Higher numbers indicate better agreement.

$$\text{Jaccard Index} = \frac{SI_{SGT} \cap SI_{AGTMO}}{SI_{SGT} \cup SI_{AGTMO}} \quad (5)$$

$$\text{Dice coefficient} = 2 \times \frac{SI_{SGT} \cap SI_{AGTMO}}{SI_{SGT} + SI_{AGTMO}} \quad (6)$$

Where, SI_{SGT} represents manually segmented ground truth road area, SI_{AGTMO} represents road area detected by proposed hybrid method. Table 1 shows the similarity coefficients results significantly good for this proposed hybrid approach for road extraction.

Another three parameters like Accuracy, V_{SGT} and V_{AGTMO} are evaluated for quality measurement. Accuracy means proportion of correctly segmented road pixels out of all pixels of segmented ground truth roads. V_{SGT} gives number of pixels in segmented ground truth voxel (region pixels) and V_{AGTMO} gives number of pixels in segmented proposed hybrid voxel.

Table 2 shows that better accuracy is achieved by using this approach. In Table 2, V_{SGT} and V_{AGTMO} parameters are representing occurrence of pixels in segmented ground truth and segmented proposed hybrid approach respectively.

Conclusions

The proposed method of integration of adaptive global thresholding and morphological operations is used to extract the road network from a high resolution satellite imagery. The major and practical merit of this approach is introducing adaptive global thresholding followed by morphological operations. Extraction of road segments has been done with the help of adaptive global thresholding, which is based on threshold limit and pixel intensity values. Then, by applying morphological operations on the segmented image, the proposed method is tested on high resolution satellite imagery of suburban area. Experimental results indicate possible use of algorithm in extracting the road network from high resolution satellite images in a reliable manner. In some cases, small part of barren land and parking area is classified as roads. The approach is based on the pixel intensity values, which induces the detection of some unwanted objects. These non-road segment areas are also removed using road tracking algorithm. The quality assessment parameters correctness and completeness values are calculated as 96.52 and 95.32 respectively, which show good degree of extraction of road network. An accuracy value of 95.94 also shows better extraction. The occurrence of pixels in segmented ground truth and segmented hybrid approach also has good matching. Still there is a requirement of some soft computing techniques to resolve the problem of extraction of non-road segments to improve this automated technique.

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