Automatic Road Network Recognition and Extraction for Urban Planning

David B.L. Bong, Koon Chun Lai, and Annie Joseph

Abstract—The uses of road map in daily activities are numerous but it is a hassle to construct and update a road map whenever there are changes. In Universiti Malaysia Sarawak, research on Automatic Road Extraction (ARE) was explored to solve the difficulties in updating road map. The research started with using Satellite Image (SI), or in short, the ARE-SI project. A Hybrid Simple Colour Space Segmentation and Edge Detection (Hybrid SCSS-EDGE) algorithm was developed to extract roads automatically from satellite-taken images. In order to extract the road network accurately, the satellite image must be analyzed prior to the extraction process. The characteristics of these elements are analyzed and consequently the relationships among them are determined. In this study, the road regions are extracted based on colour space elements and edge details of roads. Besides, edge detection method is applied to further filter out the non-road regions. The extracted road regions are validated by using a segmentation method. These results are valuable for building road map and detecting the changes of the existing road database. The proposed Hybrid Simple Colour Space Segmentation and Edge Detection (Hybrid SCSS-EDGE) algorithm can perform the tasks fully automatic, where the user only needs to input a high-resolution satellite image and wait for the result. Moreover, this system can work on complex road network and generate the extraction result in seconds.

Keywords—Road Network Recognition, Colour Space, Edge Detection, Urban Planning.

I. Introduction

IN recent years, the road network changes at a rapid rate because of urban development. Thus, it is hard to maintain the accuracy and precision of the road network. In order to execute massive applications such as city planning and management system, automatic extraction of roads for updating city map has recently come to a popular research topic [1]. Research in Automatic Road Extraction using Satellite Images (ARE-SI) has been carried out in Universiti Malaysia Sarawak. Road extraction strategies can be divided into two categories namely semi-automatic extraction and automatic extraction. In semi-automatic road extraction, all the initial points or road seeds need to be provided. However, in fully automatic extraction, the road seeds can be detected automatically and linked to complete the road network [2]. In generally, automatic way is more preferable than the manual operations that acquire lots of manpower and time in mapping the road network [3].

There are many researchers interested in this topic. Some of them propose the use of Hough Transform to detect road lines and implementing ”snake” method to reconnect the broken road lines [4]. However, Hough Transform has low efficiency in detecting curve road, and ”snake” requires user to select initial seed points to start, turning its system into semi-automatic which is more time-consuming. Furthermore, these two methods are not applicable for complex road network involving complicated curve lines.

There are alternative ways suggested by researchers. However, they only manage to extract simple road networks [5]. On the other hand, there exists some methods that can work for complex road network, but unfortunately, they always utilize long and complicated procedures before the result is gained [6].

In this project, a new algorithm based on hybrid simple colour space segmentation and edge detection (Hybrid SCSS-EDGE) is proposed for the road extraction system to solve the stated problems. It performs the extractions fully automatic and properly works on complex road networks with satisfactory results generated within seconds. The key techniques used for the algorithm are segmentation using edge detection together with colour space components (i.e. luminance, saturation and hue values) of the satellite imagery. Satellite images from Google Earth are considered because of its wide availability and less deployment cost for this project.

II. Hypotheses of Road Features

Several important hypotheses have been made for the road extraction process, as mentioned in [7], [8], [9] and [10].

a) Road width variance is small and road width change is likely to be slow.

b) Road direction changes are likely to be slow.

c) Road local average grey level is likely to vary only slowly.

d) Grey level variation between road and background is likely to be large.

e) Roads are unlikely to be short and the curvature of roads varies slowly.

f) Texture enclosed by the road edge is homogenous despite of shadows.

g) There exists connectivity between roads which forms road network.

Nevertheless, some hypotheses are not always true as road images may vary with ground resolution, road type and density of surrounding objects. Hence, in this study, the satellite images from Google Earth are captured with aerial view in a range of 1000 till 5000 feet for the sake of yielding

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Manuscript received April 21, 2009; revised June 19, 2009.

more precise extraction results by applying these valuable hypotheses.

III. Colour Space Components

The satellite images in used were captured in full colour forms. Thus, the basic RGB colour model can be utilized to study the characteristics of the satellite image. In this study, two more colour models, namely YCbCr and HSV were selected for investigations. YCbCr model, which is commonly used as digital video formats, consists of Y (represents luminance or a measurement unit of the energy amount that an observer perceives from a light source), Cb (represents the difference between the blue component and a reference value) and Cr (represents the difference between the red component and a reference value). Similarly, HSV also consists of Hue (a colour attribute that describes a pure colour like yellow, orange, or red), Saturation (a measurement of the degree to which a pure colour is diluted by white light) and Value (intensity or average value of R, G and B at specific location). Each of these components can be obtained from RGB model with the expressions as shown:

$$Y = 65.481R + 128.553G + 24.966B + 16 \quad (1)$$

$$C_b = -37.797R - 74.203G + 112.000B + 128 \quad (2)$$

$$C_r = 112.000R - 93.786G - 18.214B + 128 \quad (3)$$

$$H = \begin{cases} \theta & (B \leq G) \\ 360 - \theta & (otherwise) \end{cases} \quad with$$

$$\theta = cos^{-1}\left\{ \frac{0.5\left[(R-G)+(R-B)\right]}{\sqrt{(R-G)^2+(R-B)(G-B)}} \right\} \quad (4)$$

$$S = 1 - \frac{3}{R+G+B}\left[MIN\left(R,G,B\right)\right] \quad (5)$$

$$I = \frac{R+G+B}{3} \quad (6)$$

IV. The Hybrid SGSS-EDGE Algorithm

The overall flowchart of the hybrid SGSS-EDGE algorithm is shown in Figure 1.

A. Image Acquisition

The Google Earth satellite images are used in this project that can provide medium-high resolution imagery greater than 1-meter per pixel.

B. Road Regions Extraction

It seems that many elements can be found in a colour satellite image, however, the authors had classified them in five categories. These five general elements could be found in a high-resolution satellite image, namely: bushes or trees, roads, buildings, sandy region and water regions, as shown in Figure 2. The characteristics of these elements are studied and examined.

In Figure 2, humans can easily differentiate these five elements with their naked eyes since all these elements are

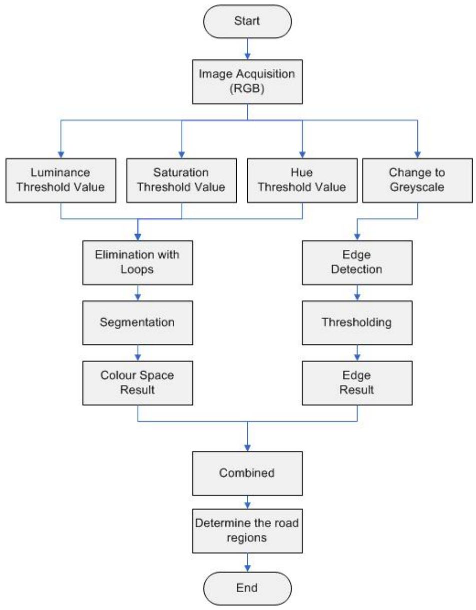


Fig. 1. Flowchart of the hybrid SCSS-EDGE extraction

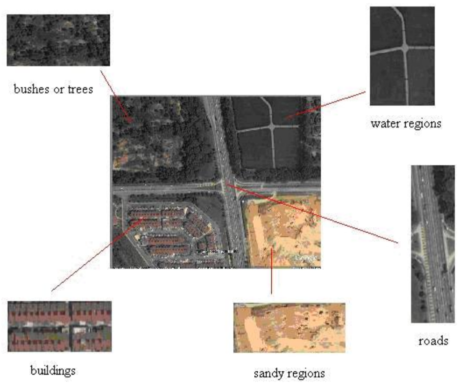


Fig. 2. Five elements in a satellite image

different from each other by their colour and luminance. For the purpose to let the computers have the same ability, they are trained to analyse the colour space components (i.e. luminance, Saturation and Hue values) of the satellite image. These components can be obtained by converting the image into YC_bC_r and HSV colour spaces. The significant relationships among them are noticed through examinations over a number of imageries. Besides, detailed records are tabulated in Table 1. Other components like C_b, C_r and Value (or intensity) are not used due to their poor abilities to provide useful information from the evaluations. The relationships among the colour space components are listed below:

a) Buildings have the smallest hue value which ranges from 0 to 0.1

b) The maximum saturation value for roads is 0.3

c) The minimum saturation value for sandy regions is 0.3

d) Bushes or trees are scattered and their luminance value is below 100

TABLE I
RELATIONSHIP OF THE 5 GENERAL COMPONENTS

	Bushes or Trees	Roads	Buildings	Sandy regions	Water regions
Luminance	25-100	110-160	50-150	100-200	50-80
Hue	0.05-0.3	0.05-0.2	0-0.1	0.05-0.1	0.1-0.45
Saturation	0.05-0.4	0.1-0.25	0.1-0.5	0.3-0.5	0.05-0.2
Intensity	0.05-0.5	0.15-0.8	0.2-0.6	0.4-1	0.2-0.3

e) Sandy regions have similar luminance value with roads
f) Water regions are well separated from roads
g) Roads' hue value is between 0.05 to 0.2
h) The range of urban road's luminance is between 110 and 160 lumens.

Therefore, in this project, the road network can be extracted out from the satellite images by applying these essential adjustments:

a) Set luminance threshold value larger than 100 to eliminate bushes or trees
b) Set Saturation threshold value smaller than 0.3 to eliminate sandy region
c) Set Hue threshold value larger than or equal to 0.05 to eliminate some buildings
d) Use segmentation to separate the water regions and other small regions from road network
e) Use edge detection to recover the broken road segments due to some undesired elimination to roads

Firstly, the satellite image is converted into YC_bC_r and HSV modes using image processing software such as Matlab program. The elimination process can be performed by setting up a pixel-to-pixel examination loop to filter the unwanted pixels. Since Y represents luminance in YC_bC_r mode whilst H, S denote as Hue and Saturation correspondingly in HSV mode, the examination loop can be thus written as

$$(100 < Y) AND (S < 0.3) AND (H \geq 0.05) \tag{7}$$

Segmentation process is performed on the image as well. Though the water regions can be eliminated by the loop described above, the segmentation can further ensure its elimination due to water regions such as lake or river will certainly not attach to the roadside or any roads. Furthermore, by only selecting the road regions, other small regions not belong to the road network can be eliminated in this process. Note that the authors always assume the road network appears as the largest connected region in a satellite image that would remain throughout the segmentation process, and only removes the relatively small regions.

C. Edge Detection

Road extraction based only on the colour space components may not be perfect. This is due to constant changes of the road's colour while being shaded by trees or buildings. Some shaded road segments which luminance value is lower than a predetermined threshold, i.e. 110 lumens, will be recognized as bushes and thus eliminated by the examination loop. Hence, edge detection is introduced in order to counter this problem. Though the colour has been changed, the edge detectors are still able to find the road edges to reconnect the undetected road segments as long as the road segments are not entirely detached or blurred.

Edges are the essential characteristic in road extraction since the roads are laterally bounded by edges and can be individuated by edge extractors [9][11]. The edges can be extracted using various edge detection methods. The image is converted into grayscale mode prior to applying the edge detector. In this project, the Laplacian of Gaussian method, as explained by equation (8), is used.

$$\nabla^2 f(x,y) = -\frac{1}{2\pi\gamma^4}\left(2 - \frac{x^2+y^2}{\gamma^2}\right) \cdot e^{\left(-\frac{x^2+y^2}{2\gamma^2}\right)} \tag{8}$$

Equation (8) is a second-order derivative which can be acquired when Gaussian method is defined as f(X), where

$$f(X) = \frac{1}{2\pi\gamma^2} \cdot e^{\left(-\frac{x^2}{2\gamma^2}\right)} \tag{9}$$

The Laplacian of Gaussian method finds edges in the input image by looking for zero crossings after filtering the input image. This method can detect the edges with different scale by altering the value, which makes it superior to other edge detection methods [9]. The threshold value for the Laplacian of Gaussian filter can then be adjusted to give better results. Figure 3 and 4 illustrates two set of results showing the importance of edge detectors in reconnecting the road network regions.

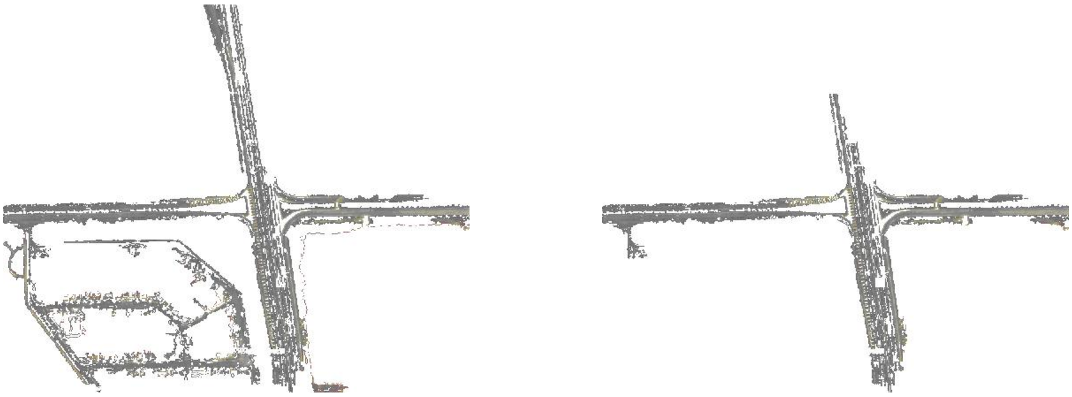
D. Determining the Road Network

Road extraction results obtained after elimination and segmentation processes are combined with the edge detection result to determine the actual road network. Based on the assumption that connectivity exists between roads that form a road network [10], the largest regions can be considered as road regions. As a result, a simple calculation on the total pixels is made to verify and select the largest connected regions in the result images.

V. RESULTS AND ANALYSIS

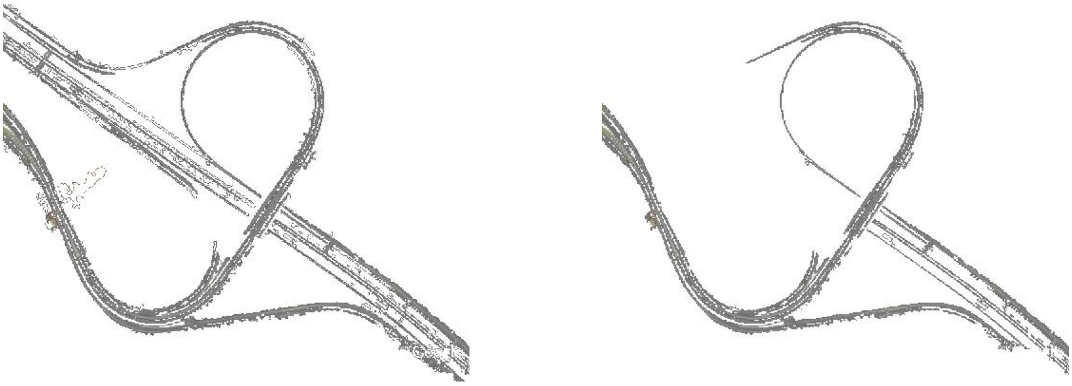
The proposed Hybrid SCSS-EDGE algorithm can work on the complex road segments and large scale satellite image with good finishing and accuracy. The satellite images captured within area in Kuala Lumpur city, Malaysia are shown in Figure 5 to Figure 9 in an increased complexity level. Figure 5 shows a straight road in rural area that surrounded by bushes and tress. The road region is perfectly extracted without any discontinuities.

On the other hand, Figure 6 shows another extraction result on a curve road region (express highway) surrounded by bushes and sandy regions. These results prove that the algorithm used in this project has a very good finishing and accurate performance on extracting the simple road regions.



(a) Using edge detection (b) Without using edge detection

Fig. 3. Reconnect straight regions



(a) Using edge detection (b) Without using edge detection

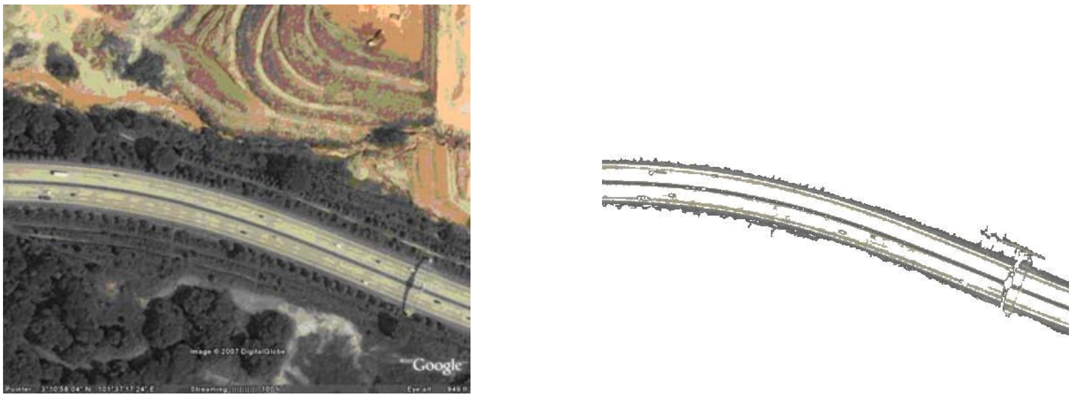
Fig. 4. Reconnect curved regions

(a) (b)

Fig. 5. Extraction for a straight road

Figure 7 displays a moderate complicated road networks in an urban area, involving multiples of curve road regions. The algorithm proposed, in fact, is still able to eliminate the unwanted regions such as buildings at top left corner and the ground fields located between the curve regions. The good performance of the algorithm is demonstrated obviously by the corresponding extraction result image of Figure 7. Discontinuity of roads at the bottom-middle part is caused by the blockade of statement put by Google Company.

The road networks in the imageries shown in Figure 8 and Figure 9 are at much more complicated level. Almost all road regions in Figure 8 are successfully extracted and displayed in the result image. Some roads failed to be extracted due to the image is captured at a vey high aerial distance (4000 feet), thus sometimes made the image blur at random spots. Figure 8 exhibits an image captured at 10000 feet. The extraction result



(a) (b)

Fig. 6. Extraction for a curved road

(a) (b)

Fig. 7. Extraction for a small scale complex road

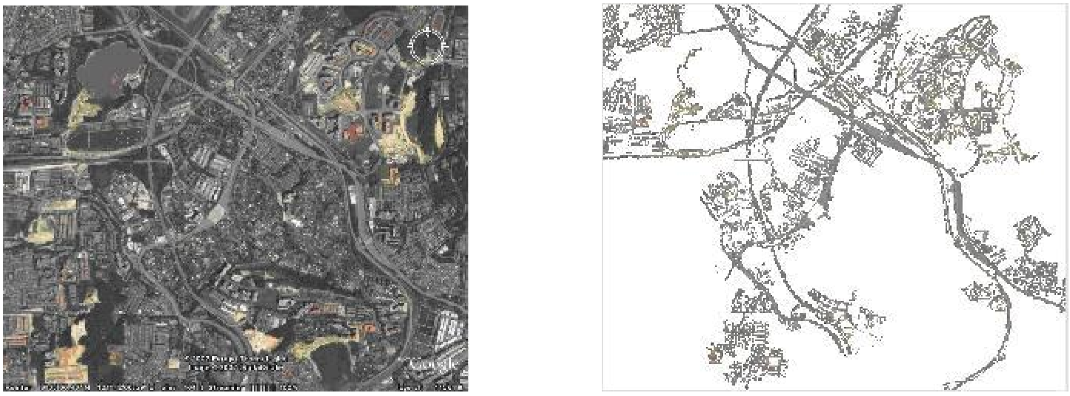
(a) (b)

Fig. 8. Extraction for a medium scale complex road

is able to give a good overview for the main road regions in the satellite image.

It is noticeable from the results that the proposed extraction method can perform at a high finishing and accuracy level. Furthermore, this suggested methodology can generate the results in a very short time. Each of these extraction outputs (Figure 5 to Figure 9) is obtained within a minute using a P4-1.8GHz PC with 256MB RAM, run by Matlab program.

Some objects, such as trees' shadow, may change the road luminance value and break the connectivity of the road regions. Consequently, some road regions are unable to be extracted as shown in Figure 8 and Figure 9. However, this problem only affects the small road regions in which their connectivity is totally broken while the main roads will not be affected. Other small roads can still be extracted as long as their connectivity to the main roads still exists.



(a) (b)

Fig. 9. Extraction for a large scale complex road

Failure on extracting the road regions in Figure 8 and Figure 9 may also due to the improper image acquisition process. These images are probably captured under cloudy or high humidity environment which caused the blurriness in the image.

Some unwanted road-like regions are extracted together with the road regions. This problem is due to the filter's disability to separate the road regions from the road-like regions. For future works, the filtering capability needs to be improved in order to yield better extraction results.

The main drawback of using Google Earth satellite image is the non-standardized image resolution. This causes problems such as luminance value of roads in different regions. Future works is proposed to overcome this issue so that the road network extraction process for urban planning and GIS database updates can be performed successfully.

VI. CONCLUSION

The road extraction process can be divided into two groups, namely automatic and semi-automatic (or manual). The automatic way is getting popular attentions due to its short processing time. The Hybrid SCSS-EDGE methodology mentioned in this study is able to extract road regions automatically, both in rural and urban areas, from high-resolution satellite imageries in a very fast way. The results can be obtained from the hybrid results from colour space elements (luminance, saturation and hue) and the edge details of roads. Besides, a number of adjustments are discussed to effectively extract the road network. The advantages of this method are its fast, accurate yet simple algorithms. In addition, it can provide valuable references for organizations or companies which deal with road maps and GPS (Global Position System).

ACKNOWLEDGMENT

The authors would like to thank Universiti Malaysia Sarawak for the facilities, resources and support given to this project, and also members from Faculty of Engineering who have contributed or helped in this project.

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