Road Detection Method for Land Consolidation Using Mathematical Morphology from High Resolution Image

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Abstract: Land consolidation is a tool for increasing the area of the arable land and improving the effectiveness of land cultivation. With the development of high resolution image, the progress of land consolidation project can be monitored by acquiring information from the image objectively. This paper presents an algorithm to detect roads in land consolidation project from high resolution images. The method is based on the mathematical morphology, which is a method for detecting image components that are useful for representation and description. The vector planning maps and high resolution images used to monitor the completion of land consolidation project are registered. The candidate road areas are created using the functions of buffer and extraction by mask in GIS. Top-hat transform and gray dilation are used to filter the noise of the image. In this way the road feature in the image became wider and even more obvious to be recognized. Then image binarization and thinning algorithm are used to extract the one-pixel centerline of the road. At last, the thinning results are converted to the final vector detection results.

Key-Words: road detection, mathematical morphology, land consolidation, remote sensing

1 Introduction

Land consolidation is a tool for improving the effectiveness of land cultivation, land productivity and also the total factor productivity if it induces and enhances technical progress and increases scale economies. Consolidation deals with a large number of phenomena, such as fields, roads, and land use, all of which exhibit characteristic forms and patterns which can be analyzed as to their existing spatial organization, or as to their changing spatial organization through time [1]. In a traditional way, The Land Charges Department usually has to survey in the study area manually to acquire the accurate changes of roads after the project which could cost a lot of manpower and resources. With the development of high resolution imagery and the improved feature detection method, remote sensing has become an effective means of land use monitoring. Road detection scheme presented by Trinder et al. [2] is based on Marr's theory of vision, which consists of low-level image processing for edge detection and linking, mid-level processing for the formation of road structure, and high-level processing for the recognition of roads. It uses a combined control strategy in which hypotheses are generated in a bottom-up mode and a top-down process is applied to predict the missing road segments. The existing road detection approaches cover a wide variety of strategies, using different resolution aerial or satellite images. The approaches are generally classified according to the degree of automation: automatic method and semi-automatic method. Semi-automatic systems assisted by an operator seem to be more effective for road detection now. However, the development trend of road detection is automatic detection system in the near future. After detecting the road network, there may be a few wrong results, which can also be corrected by the system operator.

Automatic methods usually detect reliable hypotheses for road segments through edge and line detection and then establish connections between road segments to form road network [3]. Hinz et al. [4] integrate detailed knowledge about roads and their context using explicitly formulated scale-dependent models. The knowledge about how and when certain parts of the road and context model are optimally exploited is expressed by a detection strategy. Mokhtarzade et al. [5] treats the possibility of using artificial neural networks for road detection from high-resolution satellite images on a part of RGB IKONOS and Quick-Bird images from Kish Island and Bushehr Harbor, respectively.Laptev et al. [6] proposed a new approach for automatic road detection from aerial imagery with a model and a strategy mainly based on the multi-scale detection of roads in combination with geometry-constrained edge detection using snakes.

Semi-automatic methods require operator to provide some information to control the detection interactively. Most semi-automatic approaches search for an optimal path between a few given points. Gruen and Li et al. [7] and Merlet et al. [8] connect points using dynamic programming, model-driven linear feature detection algorithm based on dynamic programming. Gruen et al. [9] developed linear feature detection method using dynamic programming and LSB-Snakes. Park and Kim [10] presented a road detection algorithm using template matching. But the limitation is that it requires initial seed points on the road central lines and each road segment requires separate seed points. Shukla's scheme is based on the cost minimization technique [11]. The cost is estimated by taking various factors into consideration such as variance, direction, length and width of the road. The process starts with the selection of seed points provided by the user. Dal Poz et al. [12] presented a dynamic programming approach for semi-automated road detection from medium- and high-resolution images, proposing a modification of merit function of the original dynamic programming approach, which is carried out by a constraint function embedding road edge properties.

The aim of this paper is to develop a road detection method based on mathematical morphology in land consolidation area. The paper begins with a brief overview of characteristics of the study area. After that, the principle of mathematical morphology is illustrated. This is followed by the road detection flow and the detail algorithm. The algorithm is implemented in the Matlab tools. Results achieved with high resolution satellite image are depicted. Finally, conclusions are drawn.

2 Study Area

The study area is located at 116° 39′ N longitude and 40° 08′ E latitude in the northeast of Beijing (Fig. 1) and is influenced in some parts by different types of land improvement works, such as reclamation, watercourse rectification and land consolidation works, which have a large impact on the rural landscape. This area is characterized by rolling topography and flourishing vegetation. One Quick Bird image, acquired on June 2006, without any clouds/hazes, is used in this study. A Quick Bird image has four multi-spectral bands (i.e. near-infrared (NIR), red, green, and blue) with 2.44-metre spatial resolution and one panchromatic band with 0.61-metre spatial resolution. Both dates of imagery were geo-referenced to a Transverse Mercator projection and Krasovsky spheroid with an RMSE of 1 pixel. It was necessary to radiometrically normalize the multiple dates of remote sensor data even though they were obtained on near anniversary dates.

Fig.1. Location of Study Area

3 Principle of Mathematical Morphology

Mathematical Morphology is a method for detecting image components that are useful for representation and description. The technique was originally developed by Matheron and Serra [13] at the Ecole des Mines in Paris. It is a set-theoretic method of image analysis providing a quantitative description of geometrical structures. At the Ecole des Mines they were interested in analyzing geological data and the structure of materials. Morphology can provide boundaries of objects, their skeletons, and their convex hulls. It is also useful for many pre- and post-processing techniques, especially in edge thinning and pruning.

Generally most morphological operations are based on simple expanding and shrinking operations. The primary application of morphology occurs in binary images, though it is also used on grey level images. It can also be useful on range images [14].

3.1 Set operations

These transformations involve the interaction between an image A (the object of interest) and a structuring set B, called the structuring element. Typically the structuring element B is a circular disc in the plane, but it can be any shape. The image and structuring element sets need not be restricted to sets in the 2D plane, but could be defined in 1, 2, 3 (or higher) dimensions.

3.2 Dilation

Dilation of the object A by the structuring element B is given by

$$A \oplus B = \left\{ x : \hat{B}_x \cap A \neq \varnothing \right\}$$

The result is a new set made up of all points generated by obtaining the reflection of B about its origin and then shifting this relection by x.

3.3 Erosion

Erosion of the object A by a structuring element B is given by

$$A \Theta B = \left\{ x : B_x \subseteq A \right\}$$

Two very important transformations are opening and closing. Now intuitively, dilation expands an image object and erosion shrinks it. Opening generally smooths a contour in an image, breaking narrow isthmuses and eliminating thin protrusions. Closing tends to narrow smooth sections of contours, fusing narrow breaks and long thin gulfs, eliminating small holes, and filling gaps in contours.

3.4 Opening

The opening of A by B, denoted by $A \circ B$, is given by the erosion by B, followed by the dilation by B, that is

$$A \circ B = (A \Theta B) \oplus B$$

3.5 Closing

Closing is the dual operation of opening and is denoted by $A \circ B$. It is produced by the dilation of A by B, followed by the erosion by B

$$A \bullet B = (A \oplus B) \Theta B$$

4 Road detection algorithm

The flow chart of road detection algorithm is described as the Fig.2. The Quick Bird image and the vector planning map are registered in the same geographic coordinate. The functions of buffer and extraction by mask in GIS are used to obtain the candidate area, which could be used to monitor whether the roads have been built up or the length of the roads. After the candidate area image was created, the filter technique is introduced to emerge the roads. The filter technique contained Top-hat transform and dilation algorithm. Then the histogram of the image was created and threshold could be calculated automatically, which is called binarize image. There might be some parcels of other objects like grass, trees, houses etc. they could be wiped off in terms of shape and area. The thinning algorithm is used and then the roads could be converted to the vector. According to the direction and the length of a road, the tiny lines are also eliminated. After the steps above, the roads are detected.

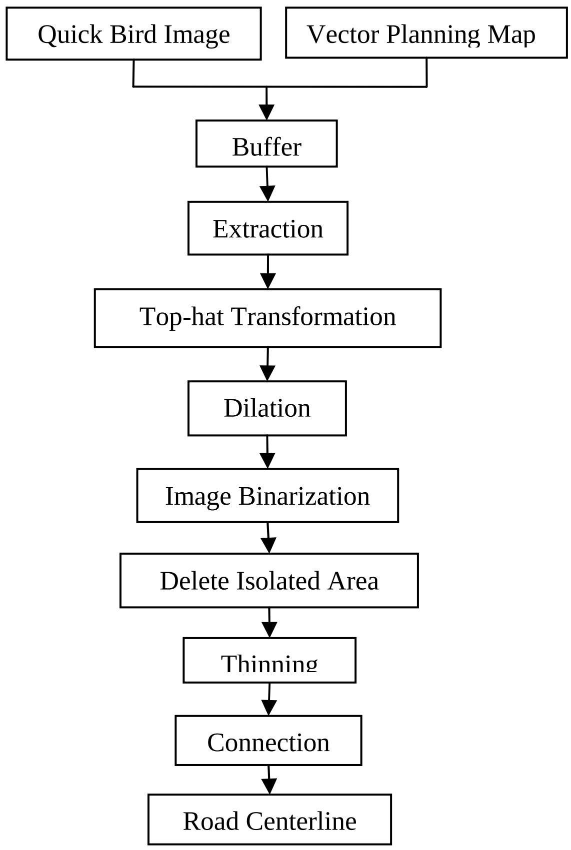

Fig.2. Road detection flow

4.1 Generating candidate area

The planning map was edited before the project, according which the roads should be constructed. There may be some roads that were not constructed as plan exactly. The road buffer is created with the width of 30m, in which most roads exist. The buffer then is used as a mask to detect the candidate area. The candidate area is shown in Fig.3.

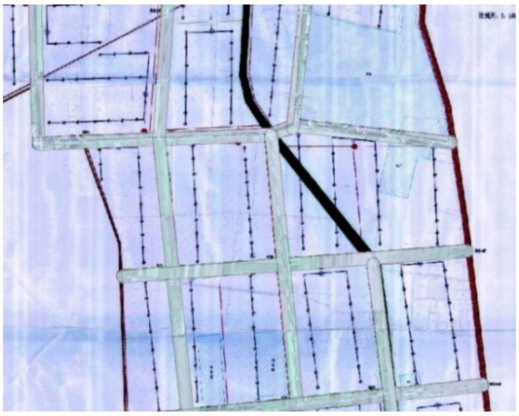

Fig.3. Candidate area

4.2 Image filter

In order to smooth the image noise, Top-hat transformation and dilation are used to make the road more recognizable.

The Top-Hat transformation is one of the gray scale morphologic algorithms and is beneficial in finding pixel clusters that are light on a surrounding relatively dark background. It can be used to find neuronal cells in a tissue sample and to detect blood vessels from an image using an X-ray system and fluorescent dyes [15]. This operation is illustrated in Fig.4. The transformation processes original signal f with opening by flat structuring element g. Fig.5 indicates that the peaks are detected as a Top-Hat by subtracting an opened image form the original image.

The opening operation includes two procedures, erosion and dilation. Because the structuring element is flat, the erosion is simplified to find the minimum gray level and the dilation to find the maximum during process. This operation seems to be able to detect the objects above the ground, but unfortunately the detectable size of object depends on the size of the element. Therefore we use this opening operation just to eliminate the peaks, like noise in elevation space [16].

The dilation operation can improve detection quality and accuracy after the Top-hat transformation.

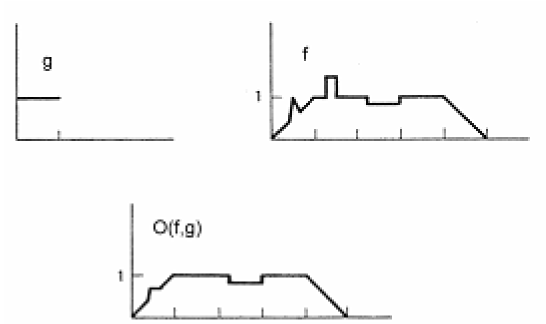

Fig.4. Opening by flat structuring element [Dougherty, 1992]

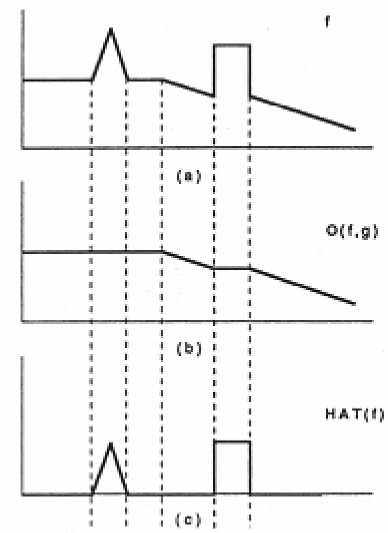

Fig.5. Top-Hat Transformation [Dougherty, 1992]

4.3 Image Binarization

Binarization of gray level images after the preprocessing is a special case of segmentation with two labels, which is the most important step of the algorithm. The purpose is simplifying the image to detect the contour. The histogram of this kind of image is described in Fig.6. According to the histogram characteristic, the threshold is calculated exactly as following [17].

From the peak of the image toward the right side:

$$T_1(t) = (p_{t-5} + p_{t-4} + p_{t-3} + p_{t-2} + p_{t-1} + p_t)/6$$

$$T_2(t) = (p_t + p_{t+1} + p_{t+2} + p_{t+3} + p_{t+4} + p_{t+5})/6$$

p_t represents the numbers of point whose gray value is t.

$$\theta(t) = \arctan[(T_1(t) - T_2(t))/6]$$

If $T_1(t) \geq T_2(t)$ *and* $\theta(t) \leq 2 \bullet \frac{\pi}{180}$, t is the threshold. There might be not one t, so the first is just the value.

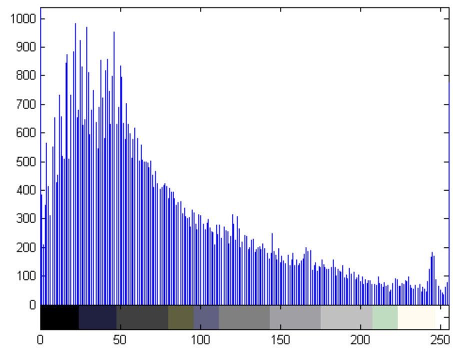

Fig.6. Histogram of image

4.4 Delete Isolated Area

There might be a few noise parcels left after the binarization operation, which need to be eliminated. The method is described as following [18]:

(1) Calculate the area a , perimeter p and shape index t of each parcel.
(2) Delete the parcel met the conditions of $a_1 < a < a_2$ and $t > 0.1$, where $r = \sqrt{a / p}$, a means the number of pixel in a parcel and p means the number of pixel in a parcel boundary. a_1 means that the most area of a parcel belong to a road. a_2 means that the most area of isolated parcel.
(3) Direction dilation

After step 2, there are some small parcel left only, but the road is still not connected. So the direction dilation operation is used to connect the discontinuous segment.
(4)Delete the small parcels

4.5 Thinning

Thinning is another mathematical morphology operation which can be used to detect the centerline. The general definition of a thinning of a set A by a structuring element S is that we remove from A a part of A specified by the hit-or-miss transform. The thinning is denoted by $A \otimes B$ and may be written in set notation:

$$A \otimes B = A - (A \circledast B)$$
$$= A \cap (A \circledast B)^c$$

The details are described in Fig.7.

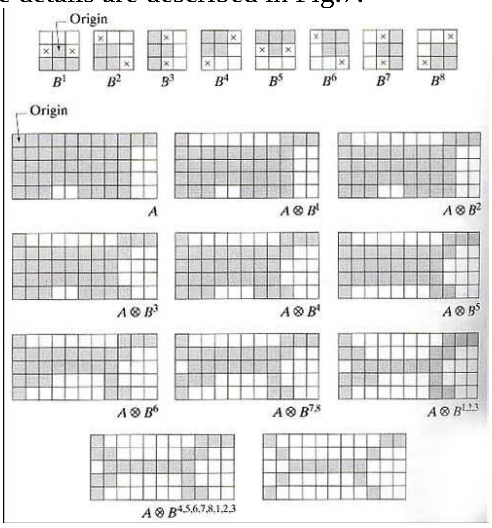

Fig.7.Thinning algorithm

5 Results

A piece of candidate area is cut as the test image in Fig.8. The selected candidate area includes typical land consolidation roads. There are also some trees along two sides of the road and the spectrum of some blocks is similar with the road.

Fig.8. A road of study area

Fig.9 shows the original RGB image has been converted to the gray image automatically in Matlab by the function of *rgbtogray*. The roads present white lines, but there still are some trees shade the edges of the roads.

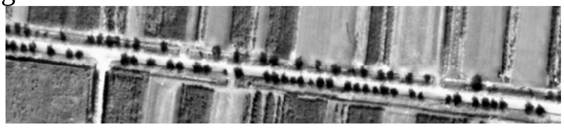

Fig.9. RGB image to gray image

After converting the RGB image to gray image, the roads need to be enhanced and the background needs to be weaken. Fig.10 shows the results after image filter which contain the Top-hat transformation and dilation. The functions in Matlab are *imtophat* and *imdilate*.

Fig.10. Top-hat transformation

Binarization is the most important step in the whole scheme because it completely differentiates the roads and background. It is a kind of image segmentation, which sets a threshold and divides the image into two parts. The threshold is acquired from the formula described above. Fig.11 and Fig.12 show that the profile of the road to be detected has been come out. The function *im2bw* is used. But there are still some gaps and redundancies.

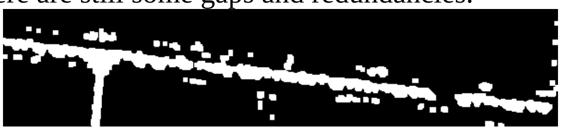

Fig.11. Image Binarization

Fig.12. Deleting Isolated Area

After the connection and thinning operation, the final centreline of road has been detected and is shown in Fig.13

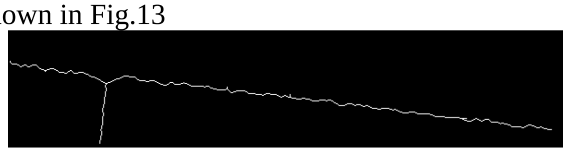

Fig.13. Thinning

Taken together, the final results of road detection scheme have been carried out with a piece of image in ShunYi land consolidation area and the results seem to be good and practical.

6 Conclusion

A method of road detection based on mathematical morphology for land consolidation has been briefly described. The mathematical morphology is easy to understand and implement. The experiment result on Quick Bird satellite image tells that our method can be one of the solutions for developing fully operational road detection system for land consolidation.

The high-resolution images are preferable due to use of width and variance information for road detection. On the other hand, the multispectral information should also be fully used. The concept of semi-automation has shown to be excellent for practical applications, as there is always an editing option when some automation fails due to low image quality, disturbances and other effects, but the automatic method should be the studied in the feature.

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