OBJECT-ORIENTED ROAD EXTRACTION BASED ON IMPROVED FCM AND SHAPE FILTER IN HIGH RESOLUTION RS IMAGERY

Jing Jin*
Jian-Wu Dang
Yang-Ping Wang
Fen-Wen Zhai
School of Electronic and information Engineering
Lanzhou Jiao Tong University
Lanzhou 730070
China
28089092@qq.com

Abstract. An object-oriented method of road extraction is proposed for high-resolution remote sensing imagery aiming to its characteristics. At first, bilateral filter is used in original imagery to smooth detail information and retain road edge; then it proposes an improved Fuzzy C-Means algorithm combined with the neighborhood information in order to deal with outliers better, so the imagery is segmented to independent objects by improved FCM algorithm; and then it filters every objects by geometric feature, after that it connects road segments to get network by region growing algorithm and executes post-processes by morphology method. The experiments show that the method can extract the road target efficiently from high resolution imagery with higher accuracy.
Keywords: high-resolution remote sensing imagery, road extraction, object-oriented, FCM, shape filter.

1. Introduction

Extracting different kinds of ground objects in remote sensing imageries (RS imagery) is an important method in constructing and updating geo-database. As main artificial ground objects in modern traffic system, roads are all-important identified objects and accurate road extraction plays a key role in GIS updating, city observation and planning and so on. According to the degree of human-computer interaction, there are two kinds of extraction methods: semi-automatic and automatic method. Semi-automatic extraction obtains seed points, road width and direction by human-computer interaction. Ribbon snake model [1] and ZiplockSnake model [2] are classic semi-automatic methods which take advantage of geometric and radiation feature meanwhile. Literature [3] proposes a semi-automatic method based on mean-shift algorithm that can extract center line accurately. In this method the seed points are chose artificially.

*. Corresponding author

As a main research domain, automatic methods extract road objects intelligently and automatically through machine learning algorithms [4]. The paper [5] can extract the road from the three-dimensional transportation network including overpass by fuzzy inference with very big time costing. A new method based on Expand Kalman filter and particle filter is proposed in [6] by which all road junctions can be detected, but the result seriously depends on the choice of model parameter. In short, extracting road network accurately and quickly from RS imagery is still a very difficult task because of complex and different road circumstance and occlusion due to shadow and other objects in the road.

The above algorithms could be classified to pixel-oriented road extraction method in which pixel is considered as independent individual and pixels' relationship are separated. In contrast, object-oriented methods consider that imagery is composed by objects that include important semantic information and relationship [7]. Besides spectral feature, high resolution RS imagery owns abundant spatial structure and texture information. The paper proposes an object-oriented method based on improved FCM for road extraction in high resolution RS imagery. At first, it achieves the purpose of "retaining edges and denoising" by bilateral filter. Then the paper proposes an improved Fuzzy C-Means (FCM) algorithm which eliminates its sensibility to noise by introduce neighborhood information to distance measurement and membership degree. It extracts road segments as road seeds through shape filter in segmented objects and then connects these road seeds into road network by region growing algorithm. At last, mathematical morphology methods are used to repair road and extract center line. The experiments prove efficiency and accuracy of the method.

2. Object-oriented road extraction based on improved FCM and shape filter

The difficulty of road extraction is that road feature would be affected by sensor type, spectral resolution and spatial resolution. In general, road has geometrical feature, radiate feature, topological features and context feature which obviously know from other ground objects. The paper obtains segmented objects using cluster algorithm by taking advantage of radiate feature, and does shape filtering by taking advantage of geometrical feature, at last connects road segments according to topological features. The algorithm flow is shown in Figure 1.

2.1 Bilateral filtering pre-process

More abundant details are provided by high resolution RS imagery, but some ground objects such as pedestrians, vehicles and traffic lines would be the noise disturbance in road extraction and then decrease the extraction accuracy. Therefore, imagery pre-process is necessary in order to smooth noise. In the pre-process, full retaining of road edge information is very useful in extraction at

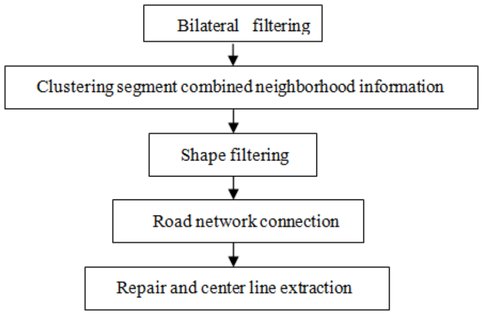

Figure 1: Flow chart of road extraction

the same time of smoothing noise. As a consequence, bilateral filter [8] is a very good choice for RS imagery pre-process. In the region with gradual change of imagery, bilateral filter will translate to Gaussian low-pass filters because of smaller intensity difference between neighborhood pixels. In the region with drastic change of imagery, original intensity value will be replaced by weighted mean of similar intensity value near the edge points. So it can achieve the purpose of smoothing the imagery and retaining edge information at meanwhile. Just like Gaussian filter, bilateral filter utilizes local weighted mean, but its weighting coefficient in 2-dimension neighborhood is a nonlinearity combination of space proximity factor ω_s and intensity similarity factor ω_r .For a center pixel $f(x,y)$, the weight $\omega(i,j)$ of pixel $f(i,j)$ in its neighborhood $N_{x,y}$ is:

$$\omega_s(i,j) = e^{-\frac{|i-x|^2+|j-y|^2}{2{\sigma_s}^2}}, \tag{1}$$

$$\omega_r(i,j) = e^{-\frac{|f(i,j)-f(x,y)|^2}{2\sigma_r^2}}, \tag{2}$$

$$\omega(i,j) = \omega_r(i,j)\omega_r(i,j). \tag{3}$$

In format (1) and (2), σ_s and σ_r are variances of two smooth factors respective by which control degree of attenuation of smooth factors. In the region with gradual change of imagery, bilateral filter will translate to Gaussian low-pass filters because smaller intensity difference between neighborhood pixels. In the region with drastic change of imagery, original intensity value will be replaced by weighted mean of similar intensity value near the edge points. So it can achieve the purpose that smoothing the imagery and retaining edge information at meanwhile.

2.2 Imagery cluster segmentation

2.2.1 Fuzzy C-means cluster algorithm

The radiation features of road include: there are bigger gradient in two edges; gray value of road region is consistent and obvious different from non-road region such as trees and buildings and so on. Hence, Fuzzy C-Means cluster algorithm [9] could be adapted to obtain all different objects by segmenting imagery. Fuzzy C-Means cluster algorithm is unsupervised classification method that applies fuzzy theory to clustering analysis and indicates level that a sample belongs to every group by membership degree without absolute “belonging to” or “not belonging to” concept. By application of fuzzy theory, FCM cluster algorithm can get better result comparing to other “hard classification” methods. The objective function of FCM is

$$J(U,V) = \sum_{k=1}^{n}\sum_{i=1}^{c}(u_{ik})^m \|x_k - v_i\|^2 , \tag{4}$$

$d_{ik} = \|x_k - v_i\|$ is Euclidean distance between cluster center v_i and sample x_k $m \in (1, \infty)$ is fuzzy weighted index number. The parameter u_{ik} describes the membership degree of sample x_k which belongs to cluster center v_i and is normalized by $\sum_c^{i=1} u_{ik} = 1, \forall k \in \{1, 2, ..., n\}$ .The algorithm searches cluster centers V and membership matrix U iteratively in order to minimize objective function J:

$$u_{ik} = \frac{1}{\sum\limits_{j=1}^{c}\left(\frac{\|x_k - v_i\|}{\|x_k - v_j\|}\right)^{\frac{2}{m-1}}} \quad 1 \le i \le c, 1 \le k \le n, \tag{5}$$

$$v_i = \frac{\sum\limits_{k=1}^{n}(u_{ik})^m x_k}{\sum\limits_{k=1}^{n}(u_{ik})^m} \quad 1 \le i \le c. \tag{6}$$

In imagery segmentation, cluster process use color values of three channels as samples feature and initialize cluster center or membership matrix.

2.2.2 Improved FCM combining neighborhood information

There are some shortages in traditional FCM algorithm: ① The choice of initial cluster centers will influence the algorithm performance; ② The algorithm is sensitive to isolated points and illumination and noise will affect segmentation result. Therefore traditional FCM method cannot eliminate noise influence from isolated points. The accuracy of later road extraction will be reduced because that objects from inefficient segmentation method are not accurate enough. Consequently, an improved FCM method is proposed in paper that combines spatial distance information and neighborhood gray difference information.

The standard FCM algorithm does not take influence from neighborhood pixels to center point into account when it computes distance between the pixel and cluster center from which FCM is sensitive to isolated points. Through analysis to standard FCM, the clustering performance depends on membership degree u_{ik} and distance d_{ik} between the cluster center and the point to be classified. For this reason, the paper introduces neighborhood information to simplex Euclidean distance and corresponding membership degree u_{ik} as well. Whether the pixel belongs to road region is relative to its spatial position in road detection of remote sensing imagery. An isolated point has bigger probability to be a road edge if all neighborhoods belong to road. The paper adjusts average weighted value to new weighted value that combines spatial neighborhood information and neighborhood gray difference information in the round, by which influence from neighborhood to center pixel becomes smaller with the increase of their spatial Euclidean distance and with the increase of their gray difference value. The distance $d_{ik}^{N_k}$ combining neighborhood information and neighborhood gray difference information is defined by format (7):

$$d_{ik}^{N_k} = \|x_k - v_i\| + \sum_{l \in N_k} w_l \|x_l - v_i\|. \tag{7}$$

If the overlarge weight is given to neighborhood information, the segment precision will reduce. In order to keep the balance between neighborhood information and gray difference, we split the weight equally.So w_l is defined as

$$w_l = 1 - \frac{1}{2}\left(\frac{d_{kl}}{\sum\limits_{l \in N_k} d_{kl}} + \frac{S_{kl}}{\sum\limits_{l \in N_k} S_{kl}} \right). \tag{8}$$

The parameter N_k is the selected window with $N \times N$ size. The parameter d_{kl} is Euclidean distance between center pixel k and the pixel l that fall into N_k . The parameter S_{kl} is gray difference value between l and k . We can see from (8) that the weight is equally split between distance information and gray difference information.

Therefore, cluster center v_i^N and membership degree u_{ik}^N can be defined by follow formats:

$$u_{ik}^N = \frac{1}{\sum\limits_{j=1}^{c} \left(\frac{\|x_k - v_i\| + \sum\limits_{l \in N_k} w_l \|x_k - v_i\|}{\|x_k - v_j\| + \sum\limits_{l \in N_k} w_l \|x_k - v_j\|} \right)^{\frac{2}{m-1}}} \quad 1 \le i \le c, 1 \le k \le n, \tag{9}$$

$$v_i^N = \frac{\sum\limits_{k=1}^{n} \left(u_{ik}^N\right)^m x_k}{\sum\limits_{k=1}^{n} \left(u_{ik}^N\right)^m} \quad 1 \le i \le c, 1 \le k \le n. \tag{10}$$

The new objective function is

$$J^N(U, V) = \sum_{k=1}^{n} \sum_{i=1}^{c} (u_{ik}^N)^m \|x_k - v_i^N\|^2. \tag{11}$$

The improved FCM algorithm can be used in handling remote sensing imagery including noise. When noise point is center pixel, it can adjust its membership automatically to avoid mistaken classification as a result of influence from a number of normal neighborhoods. At mean while, the algorithm can reduce influence from neighborhood noise points to normal pixels classification maximally so that enhance ability of noise suppression and decrease false alarm rate. The algorithm process is:

(1) Determination of parameters: classification number C , weighted index number m , termination error ε and iteration number *loop* ;

(2) Initialize membership matrix $U = \left[u_{ik}{}^{N}\right]_{c\times n}$;

(3) Compute objective function value $J^{N}(U,V)$. If difference value from last objective function value is lesser than ε or iterations times reach to threshold , the algorithm process will stop. Otherwise, the flow go to the step(4);

(4) Compute new cluster centers v_i^N , then return to step (3).

The improved FCM algorithm can be used in handling RS imagery including noise. The Figure 1(a) is original image that to be segmented with 466 $\times$ 540 size. There are some outliers in the original image. These outliers will lead to too fragmentized segment result that is not conducive to extract objects in RS imagery. The Figure 1(b) and Figure 1(c) are segment results of traditional FCM and our improved FCM method respectively. Obviously, in improved FCM algorithm the outliers can be managed better due to combination of neighborhood information.

(a) (b) (c)

Figure 2: Segmented results of traditional FCM and our improved FCM method

2.3 Object filtering combining shape feature

The road has some distinguishing features comparing to other ground objects. For example, total area is not too small and it is always spindly and so on. Therefore, specific shape features could be used in filtering segmented objects in order to obtaining candidate road segments. The following features can be utilized in shape filtering such as Area$S$, Length-width ratio$R$, Filling degree$F$,Shape factor$e$,Length$L$ and Width$W$.

Area$S$: pixel total number of every segmented object. We can set area threshold to exclude disturbed objects that are too small. The threshold T_s can be set by combining resolution of remote sensing imagery.

Length-width ratio $R : R(R = L_{ext}/W_{ext})$ is the length-width ratio of minimum bounding rectangle of segmented objects.

Filling degree $F : F = S/S_{est}$. It is the pixels ratio in object and minimum bounding rectangle at mean while.

Shape factor$e$: It describes the perimeter of unit area of object. The bigger e value indicates more complicated shape, and vice versa. For example, e value of circle is 12.6, e value of square is 16 and triangle is 20.8.

Length L and Width W : L and W is length and width of object minimum bounding rectangle corresponding. The two features can filter other lathy ground objects such as rivers and building roof.

2.3.1 Road network connection

The topological property of road means that road segment will constitute connected road network without sudden interruption. Therefore, the road segments obtained by shape filtering should be connected to network. The region grow algorithm [10] can be used to construct road network.

At first, some seed points from edges of candidate road segments are selected randomly. Then the method searches pixels of 4-neighborhood from every seed point. The pixels whose gray difference is smaller than threshold T will be added to increased region. Then this pixel will be a new seed point and same search process will begin from it. The process is repeated until all seed points can not satisfied the condition. The method can merger similar regions furthest and then connect candidate road segments ideally. The algorithm flow is showed in figure 2.

2.3.2 Extraction of road center line

After obtaining road network, we should thin road to gain center lines. There are some holes in the extracted road surface resulted from spectral difference and they will be closed-loops after thinning. It is necessary to carry post-process to them. At first, close and dilation operation of morphology are used to fill holes. Then the thinning process will get good result. After thinning we remove short lines (burrs) by method of iterative endpoints removing [11].

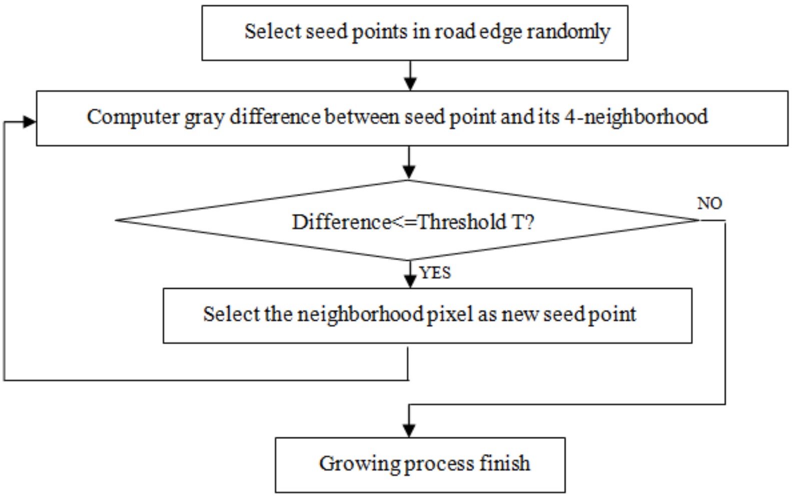

Figure 3: flow chart of region grow algorithm

3. Experiments and result analysis

At first, it choices a RS imagery of the urban area of Zhejiang from World View satellite with 0.3m spatial resolution and 280×430 size in 2012 as the first experiment data. As shown in Figure3 (a), the imagery includes different kinds ground object such as house roof, grassland, soil and roads and so on. At the same time, there is a long and narrow area in the imagery that has same spectral feature with road area. Generally, N is equal to 2 (the half width of bilateral filter). It means the size of filter window is 5×5. When $\sigma_s = 2$ and $\sigma_r = 0.1$, the imagery can get the better result of retaining edges and reducing noise by repeating experiments and summarize. The cluster number k of Improved FCM is equal to 5.The fuzzy weighted index $M = 2$. All parameters of shape filter are set by repeating experiments respectively: the area threshold=20; the Length-width ratio $R = 5$; Filling degree $F = 0.4$; the Shape factor $e = 18$; The Length $L = 50$ and Width $W = 10$.

The original imagery is handled by graying process and bilateral filter. From the pre-processed imagery in Figure 3(b), it can be seen that vehicles and pedestrians in the road are blurred and edges of road and buildings are retained well. Figure 3(c) is segmented result by improved FCM after 100 times iteration. The Figure 3(d) is the binary imagery after extracting road objects and thresholding. Then, every connected region is filtered by shape feature. The roughly extracted roads are showed in Figure 3(e). The road segments are connected to network by region growing algorithm which is showed in Figure 3(f). After final post-process by morphological method, the road center line is extracted as showed in Figure 3(g). Because of efficient pre-process by bilateral filter and more accurate segmentation by improved FCM algorithm, the method can extract main road correctly through getting rid of the ground objects that have same spectral feature to roads.

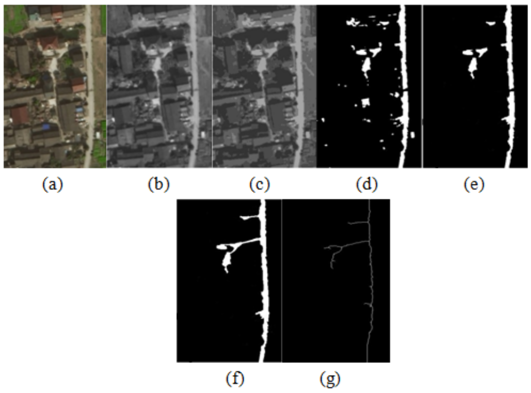

Figure 4: Results of experiment in urban road

In order to verify universality of the algorithm, the second experiment extracts the roads from RS imagery of rural circumstance. The original imagery with 660×396 size is showed in Figure 4(a). In the imagery, there are woodland and farmland with vegetational cover, bare land and roads. In the bottom right of road, a part of bare land has similar spectral feature to road. The half width of bilateral filter is 2(the size of its window is 5×5). Through repeating experiments and summarize, we get better result when $\sigma_s = 2$ and $\sigma_r = 0.1$. The cluster number k of Improved FCM is 4.In the similar way, $m$is equal to 2. All parameters of shape filter are set by repeating experiments respectively: the area threshold=60; the Length-width ratio $R = 8$; Filling degree $F = 0.4$; the Shape factor $e = 18$; The Length $L = 80$ and Width $W = 20$. The result imagery after bilateral filtering is showed in Figure4 (b). Figure4 (c) is clustered imagery and Figure4 (d) is binaryzation process result to segmented road respectively. The Figure 4(e) is obtained after shape filtering and holes filling by morphological method to binaryzation imagery. The experiment cuts the step of road network connection because that successive road network has been finished. Finally, the center line of road is showed in Figure 4(f) after thinning and eliminating burrs. The efficiency of eliminating burrs is ideal in this experiment because of the regular shape of the road. Therefore, the method can extract completed road from RS imagery in rural scene as well.

4. Conclusions and future work

The paper proposes an object-oriented road extraction method in high resolution RS imagery, which introduces the improved FCM algorithm combining neighborhood information in extraction process. The improved FCM algorithm adjusts average weighted value to new weighted value that combines spatial

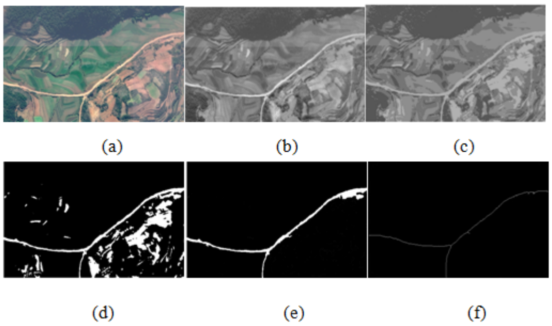

Figure 5: Results of experiment in rural road

neighborhood information and neighborhood gray difference information in the round. The experiment result indicated that it can deal with outliers better compared to traditional FCM which will avoid too fragmentized segment result that is not conducive to extract objects in RS imagery. The paper obtains independent objects by improved FCM through imagery segmentation and then generates road network combining geometric features and topology features. At last, the extracted road is repaired and thinned by morphological method. Through experiments and analysis, the proposed method can extract road goal from imagery clearly and completely. In future work, other features should be taken into account in objects segmentation and the self-adapting mechanism for threshold selection should be established combining machine learning method.

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