SEMI-AUTOMATIC DETECTION AND ENHANCEMENT OF LINEAR FEATURES TO UPDATE GIS FILES

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ABSTRACT

This paper describes a program developed to allow semi-automatic detection and enhancement of linear features in aerial photography. The program employs three different edge detectors namely Sobel, Deriche and Canny as well as morphological operations. The effectiveness of each of these operators and mathematical morphology is compared. Classification accuracy evaluation demonstrated that the Canny edge filter gave best results among these algorithms. The program is able to extract roads, field boundaries, and rivers to update GIS databases.

1   INTRODUCTION

Mapping of road networks is a topic of interest to both the Geographic Information Systems (GIS) and remote sensing (RS) communities. The problem of keeping road network files up to date is most acute in the urban fringe of major urban areas where development processes are most concentrated.

A program, called the Interactive Linear Feature Detection Program (ILFDP), was developed for semi-automatic linear feature detection using different edge detectors and morphological operations (Forghani, 1997a). Three different types of spatial filters were employed in the program: a) noise removal filters b) edge detectors (Sobel, Canny and Deriche) and thresholding, and c) mathematical morphologic transformations.

Aerial images were processed using ILFDP implemented in MATLAB. ILFDP is able to extract edges of roads, field boundaries, and rivers. The extracted edges can be used to update GIS databases.

The purpose of the program is to bring together a set of routines into an easy interactive 'suite' of programs to enable the user to optimise edge detection. Different edge detection filters and thresholding values can be compared in order to find out which filter and process is most effective and efficient for particular imagery.

2   BACKGROUND

Image processing techniques include certain types of image segmentation such as edge enhancement, edge detection and mathematical morphology.

2.1   Edge Detection

Edge detection refers to the identification in an image of edges such as object boundaries, or abrupt changes in surface orientation and material characteristics (Van Der Hejin, 1995). Trade-offs between edge detectability, noise sensitivity, and computational efficiency are often involved in selecting a suitable edge detector for a given application. Edge detectors generally suffer from weaknesses not only in sensitivity to noise, but also in poor performance near corners of structures (McKeown and Zlotnick, 1990). A successful edge detector for image segmentation depends upon a number

of criteria. These include edge continuity, minimal width (sharpness), accurate location, and completeness in terms of discriminating all relevant edges. The literature describes many edge detectors. Typical examples are Sobel, Roberts, Canny, and Deriche edge detectors. There is, of course, no shortage of literature dealing with the edge detection problem. Numerous authors have surveyed and applied edge operators, among them Fischler et al (1981); Schanzer et al (1982); Canny (1986); Deriche (1990); Gonzalez and Wintz (1987); Pratt (1987); Argialas and Harlow (1990); Monga et al (1991); Mason and Wong (1992); Faugeras [13]; Petrou (1993); Domenikiotis (1994); Aghajan and Kailath (1994); Forghani et al (1997), Forghani (1995, 1997a and 1997b.

2.2 Thresholding

After applying an edge detector, the result produced is noisy. Thresholding is one of the most frequently employed processes for classifying a pixel as an edge or non-edge (background) pixel from filtered images. Fine tuning of the threshold is crucial in order to optimise the display of edge features. However, it is a tedious task and difficult to define a best threshold. Faugeras (1993) says *"there is no good answer to this question, and the* [threshold value] *must be guided by application and the lighting conditions of the scene"*. The threshold (T) value depends mostly on image content, image quality, image geometry, and the amount of noise present in the data (Rosenfeld and Kak, 1982). If the threshold is set too low, there will be many dominant edges, points, and lines; while if the threshold is set too high, there will be some dominant features from which much useful information is removed.

Hysteresis thresholding of Canny's edge detector provides one solution to this problem. The optimal threshold for Canny's operator has been reported to be 70 to 80 percent (Canny, 1986, Guestari, 1995) using hysteresis thresholding. Experience has shown that the output of edge and line algorithms decreases significantly if the line or edge detectors are applied to imagery of urban scenes in comparison to rural areas (Forghani et al 1997; Geman and Jednynak, 1996; Forghani, 1997b).

2.3 Mathematical Morphology

A considerable effort has been made to examine mathematical morphology as a tool for delineating linear structures from remotely sensed data (Forghani, 1997b; Yokoya,1981; Destival, 1986; Forghani, 1997a). The traditional approach of mask convolution was first combined with mathematical morphology by Destival (1986). The results of this approach can be fragmentary and error-prone (Wang and Liu, 1994; Forghani, 1997a), with difficulties arising because of the number of human interpretations required for rejoining and reconstructing line segments (Destival, 1986). As mentioned earlier, the linear features in an urban area are very complex, and the use of mathematical morphology can be affected by the complexity of the scene and because of noise in the data. To overcome these ambiguities and improve the accuracy of the output, domain knowledge and global information about roads and surrounding areas can be used. Noise responses may be largely removed by discarding all responses that do not rely on either near or edge borders. Simultaneously, gaps in the lines can be filled by joining line pixels into continuous lines. Edge linking is a well known technique. The method is to find local edge pixels using some low-level process, and to join them into contours on the basis of proximity and orientation.

Possible tools for morphological operations are: bottom hatting, bridging, cleaning, closing, diagonal filling, dilation, erosion, gating, filling, horizontal breaking, opening, removing, shrinking, skeletonization, spurring, thickening, thinning, and top hatting (Mathworks, 1995). Further details on the principles of mathematical morphology are presented by Serra (1988).

3 LINEAR FEATURE DETECTION AND ANALYSIS

3.1 Program Functions

The ILFDP was implemented in MATLAB. The input for this program can be either remotely sensed imagery or other types of digital photographic data. In this study, aerial images were processed for detection of linear features. Five different types of spatial tools were implemented in ILFDP:

1. Standard histogram manipulation techniques.
2. Noise removal filters, namely Wiener and Median. The user is able to apply different filter sizes for median filtering (eg 3 by 3, 5 by 5, 9 by 9). If the presence of noise in images is ignored, then edge detection is primarily based on intensity gradients and subsequent thresholding of their magnitude. Non-linear edge enhancement algorithms are based on gradient operators.

3.   Edge detectors (Sobel, Canny and Deriche) and thresholding. The Sobel can be applied in both vertical and horizontal directions. The Canny has different mask sizes (eg 3 by 3, 9 by 9, 21 by 21). Using a Deriche filter, the user has three options for the size of the filter or local maxima (a).

4.   Thresholding can be done interactively. Different threshold values can be tested to gain satisfactory results.

5.   Mathematical morphologic transformations. The ILFDP allows the user to apply mathematical operations for the binary data (Mathworks, 1995) using five basic functions, namely dilation, skeletonization, bridge, fill, and close. These operations help increase accuracy of linear feature detection.

3.2   Data Analysis

3.2.1   Pre-Processing

A subset of a rural area (180 row by 160 column), a subset of a built-up area (185 row by 235 column), were selected from an aerial photograph for image segmentation analysis (Figure 1). Primary processing of the data was undertaken including standard image histogram stretching and median filtering techniques.

If image smoothing and noise removal is not employed on the image, problems may occur in edge detection. The effects of noise on the responses of different operators can be suppressed by smoothing the image with a low pass filter before applying an edge operator. Median filtering with a 3x3 kernel was used to reduce "salt and pepper" type noise, and remove outlying pixel values. Thus it minimised the influence of noise, and produced a smoother image. Too large a filter eg bigger than 7x7 may cause fuzzy images which are not appropriate for edge detection. This especially occurs where edge density is high and complex such as in urban areas.

3.2.2   Edge Detection and Thresholding

The Sobel, Canny, and Deriche operators at different threshold values were compared. The Sobel edge masks as a conventional technique which estimates two components of the intensity gradient vector. These masks were used to detect the horizontal and vertical edges within the image. The Sobel edge finding method in the ILFDP uses a default estimator that consistently produces good results.

As noted, the optimal threshold for Canny's operator was reported by other researchers to be 70 to 80 percent using hysteresis thresholding (Guestari, 1996). However this may be too high for some imagery including that used in this research. The hysteresis thresholding of Canny tries to keep the edge pixels as continuous as possible. The above threshold (70% to 80%) may lead to unconnected edges and may remove useful information. It was necessary to experiment with different threshold values for a homogeneous test area (eg the rural site), and a heterogeneous area (eg the built-up site). Refer to Table 1 for quantitative results.

The Deriche filter has not been widely experimented with for RS imagery. The results of the Deriche approach have been applied to the test area with a range of thresholds. In the ILFDP program, the user has three options for the size of the filter (a), and it was found that a = 2 had the best performance over images here. The Deriche operator was applied to variety of images with different values of the parameter a controlling the width of the impulse response. It was found that too many edge points were detected, particularly in regions where the contrast was low (Forghani, 1997a). Lower threshold values present too many pixels which are not true edges. Higher threshold values cause breaking of connected chains of edge pixels into chains, which is not highly desirable. It was found that lower thresholds produced too many edges, particularly in the southern part of the image where the contrast is fairly low. For example, the best threshold value for the rural site was 20-40 percent, and for the urban site was 30-50 percent using a Deriche filter. Threshold values of 35, 40, 45 percent were applied to evaluate the edge detection result for the whole image (refer to Table 1). Consequently a 40% threshold obtained reasonable results to carry out morphological transformation in order to generate a final classified map.
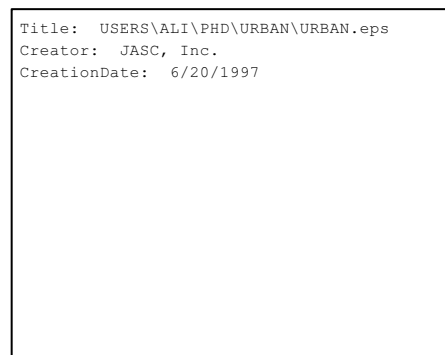
Using Canny and Deriche edge detectors requires higher threshold values for built-up areas in comparison to rural areas. To satisfy this objective, three thresholds T_1, T_2 and T_3 were used. It was found that by increasing the threshold values, the roads begin to disconnect, while significant aggregation of distinct features (eg adjacent houses) remains. A low threshold causes better road connectivity but blurs houses into roads. More conservative thresholds produce neater road segments, but leave gaps, eliminate small roads, and still some building and driveways are attached. It was found that the Canny edge detector (with a filter size of 7) and Deriche operator (with a filter size of a = 2) using a threshold value of 40% yielded more road boundaries, and tended to trace closed contours around houses.

After empirical testing, it was found that thresholding of between 20 to 30 percent over a rural site, and 40-50 over a built-up area produces edges which most closely correspond to real road boundaries. Details of the analysis are

presented in Forghani (1997a). Based upon qualitative and quantitative assessment of edge detection results, a threshold value of 40% was chosen to apply over the entire image of the study area which can be seen in Table 1. Morphological transformation was undertaken over this data for generation of the classification map.

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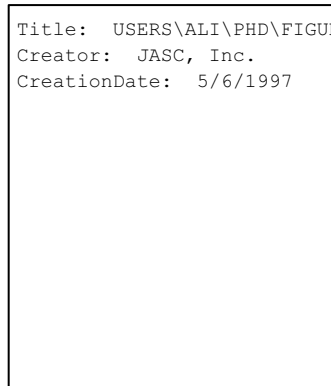
(a) 180 row by 160 column of a rural site

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(b) 185 row by 235 column of a built-up area

Figure 1. Test images; sub-sections of the 1982 image

3.2.3   Morphological Transformation over Edge Detection Data

The mathematical morphology tools are exploited after edge detection and thresholding to improve the edge detection output. To clarify the functions of mathematical tools, the results of these operations are illustrated in Table 1. After finding the best filters, threshold, the image analysis process (eg using Canny and MO) has been performed over the entire image of the study area which can be seen in Figure 2a and 2b.

Five basic transformations of binary image are used in this process in the following order: bridge, fill, close, dilation, and skeletonization. A single iteration was used for each operation. Bridge was used to bridge previously unconnected pixels; fill isolated interior pixels; close performed binary closure in the data; dilation was used to add 8-connected pixels to the boundary of binary objects. It helps to join edge segments within the binary image; the thinning (eg skeletonization) algorithm keeps the connectivity of the lines on an image. These operations increased the accuracy of linear feature detection.

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Figure 2a. The result of Canny filtering for different threshold values with a filter of 7 by 7

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Creator:  JASC, Inc.
CreationDate:  6/24/1997
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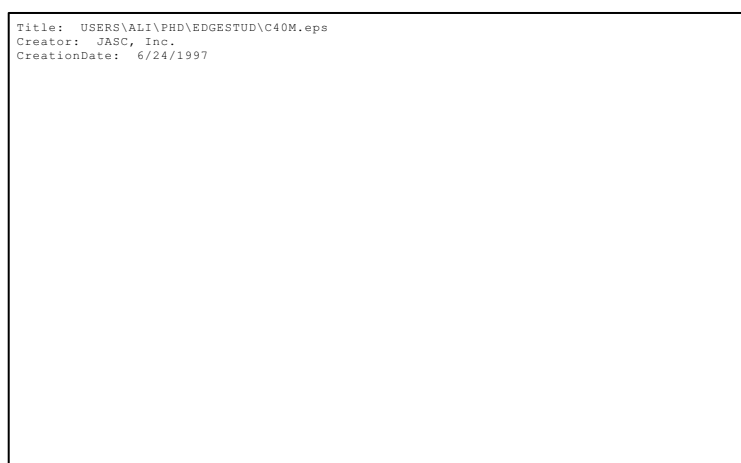
Figure 2b. Morphological operation on detected edges from Canny filtering

4   DISCUSSION

Three edge detectors namely Sobel, Canny, and Deriche were tested on subsets of the aerial image. The performance of the Sobel filter was generally lower than the Canny and Deriche filters. Based upon this, the analysis over the entire image was undertaken on the Canny and Deriche edge detectors. Results showed that Canny was marginally better than the Deriche operator (see Table 1). In respect to thresholding values, if threshold = 10% is used, many isolated spots are also picked out, because the threshold is too low. However when a higher threshold (eg threshold = 20), is chosen, there is much less noise, but similar roads are missing too.

Classification accuracy evaluation helped to choose the best edge detection filter, and threshold parameters. According to previous experimentation with the test sites, it became possible to optimize the process of linear feature detection by means of edge detection filter and thresholding. Using the Deriche edge detection filter (a = 2) and Canny operator employing three different threshold values based on the introductory experiment demonstrated that a threshold of 40% would the most subjective threshold to be applied for the whole image.

Using Canny and Deriche filers, significant confusion occurred between cleared land, construction, buildings, and other natural line features (eg field boundaries), as evidenced by high classification commission errors and omission errors for (76% and 34% respectively). Refer to Table 1, as well as (Forghani, 1997a) for details. This is not surprising because cleared areas, man-made features and natural line features occur within the spectral make-up of road edges. Both Canny and Deriche filters generated very similar results. However, it is clear that the Canny edge filter has lower omission errors compared with the Deriche operator.

Edge Detectors Data Type	Classified	Edge of Road	Networks
	Overall Classification Accuracy (%)	Omission Errors (%)	Commission Errors (%)
Canny, T = 35%	74	26	67
Canny, T = 40%	78	22	70
Canny, T = 45%	80	20	76
Canny, T = 40% and MO	86	34	35
Deriche, T = 35%,a = 2	70	30	61
Deriche, T = 40%,a = 2	75	25	69
Deriche, T = 45%,a = 2	73	27	75
Deriche, T = 40% and MO	77	33	43

Table 1. Accuracy Evaluation of the Canny, Deriche, and Morphological Operations

In order to demonstrate the quantitative assessment of image segmentation, the classification accuracy for each edge detector, threshold value, and morphological operations (MO) for both rural and urban test sites were computed. Details can be found in (Forghani, 1997a). Accuracy evaluation was based on coincidence computations between the existing road map and the classified edge detection map for the aerial imagery. This type of approach for image segmentation accuracy evaluation is widely used (Forghani, 1997a). The image segmentation accuracy of an extracted feature type are defined as the number of correctly classified pixels divided by the total number of pixels in the image. The errors of omission is defined as one minus the image segmentation accuracy. The commission errors of a detected feature type (roads and edges) are defined as one minus the number of correct non-road pixels divided by the total number of pixels in the image.

It has to be acknowledged that RS images, particularly in urban scenes, are very complex. The use of spatial filtering can be affected by the complexity of the scene because of noise in the data. Materials along the road with the same intensity as the road are problematic where there are objects with similar intensity as roads. This problem also occurs at intersections where two roads with similar material meet. If the area is a mixture of urban and residential, then the problem of feature detection becomes much more difficult. Edge detection and mathematical morphology have been used; however the output is noisy and incomplete in high density residential areas. The noise effect is a common problem in road detection. Noise causes small isolated pixels to be recognized as roadlike segments. In the process of removing noise, small segments or real roadlike structures might be missed.

5   CONCLUSION

A number of edge detection techniques and morphological operations have been examined. The ILFDP program presented here is the first step of a more complex process of pattern recognition in road networks and linear features mapping. This program is able to detect edges of roads, field boundaries, and rivers. The processed data (after morphological operations) can be used to update GIS files.

There are a number of advantages working interactively in the edge detection process such as:
1.   Preprocessing of the data using standard histogram manipulation function and noise removal is easier.
2.   Edge detection applying different filters and thresholding optimised the results. Difficulties in selection of a "right threshold" or "better" threshold value is overcome since a major limitation of line and edge filters is the need for optimal selection of thresholds for feature extraction.
3.   Morphological transformation functions improve the edge detection output.

The traditional approach of mask convolution has been combined with mathematical morphology operations. The result of this approach remains fragmentary and error-prone. The major limitation of low level image analysis techniques is use of brightness values only in the image rather than spatial and contextual information available from both humans and GIS data. To overcome these ambiguities, domain knowledge and global information about roads and surrounding areas should be used (Forghani, 1997b).

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