Applying a Wavelet Method and LINDA for Extracting Detailed Cartographic Features from High Resolution Images

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Abstract - Small topographic linear features provide important information for detailed mapping and Geographic Information System (GIS) applications. However, the collection of these features is often done by manual digitization which is labor intensive and time consuming. In this paper, methods are developed and applied to automatically extract small linear features from high resolution remotely sensed images. The extracted linear features are compared with the large scale digital map data of Great Britain and the results are promising.

I. INTRODUCTION

Small topographic linear features such as footpaths, unsurfaced tracks, hedges and fences, are difficult to automatically extract from remotely sensed data even when very high spatial resolution (for example, 20 cm) aerial photographs are available. These features provide important information for detailed mapping and Geographic Information System (GIS) applications. However, the collection of these features is often done by manual digitization which is labor intensive and time consuming. With an ever-increasing demand for spatial data that is current, detailed and of high quality there is a growing requirement to extract specific topographic features in an increasingly automated and efficient manner (Wang and Zhang, 2000).

Efforts have been made to automatically extract linear features such as roads from satellite images. Among the commonly used methods are dynamic programming and snakes (Merlet and Zerubia, 1996; Gruen and Li, 1997), an active testing model (Geman and Jedynak), neural network approach (Bhattacharya and Parui, 1997), and a sequence of algorithms (Karathanassi et al. 1999). Satellite and airborne SAR images have been used to extract roads using various algorithms (Tupin et al., 1998; Chanussot et al. 1999; Toutin, 2001; Dell’Acqua and Gamba, 2001; Jeon et al. 2002). Some algorithms have been developed to recognize roads and other objects from high resolution aerial imagery (Barzohar and Cooper, 1996; Gong and Wang, 1997; Baumgartner et al. 1999; Laptev et al. 2000; Auclair et al. 2001; Katatzis et al. 2001).

The Wavelet transform technique has been used for edge detection (Mallat and Zhong, 1992; Mallat and Zerubia, 1996; Hsieh et al. 1997; Aydin et al. 2001), but not particularly for linear feature extraction from aerial photography. The basic requirement of a wavelet function is that the integral of the function over $(-\infty, \infty)$ is zero (Mallat and Zhong, 1992), although an admissibility condition is imposed in the multi-resolution analysis of wavelet transforms. A Wavelet transform based linear feature extraction method was presented by Chen et al. (2004). This method was used to extract road networks in an urban area.

The Linear Feature Network Detection and Analysis system (LINDA), developed by Wang (1993), was used to extract a variety of linear features, such as road networks, drainage networks and geologic lineaments. In the past, some success was achieved to extract some linear features from medium to low resolution satellite data (Wang and Howarth, 1990; Wang et al., 1992; Wang, 1993; Wang and Liu, 1994; Wang, 1995.)

In this paper, the LINDA and the Wavelet methods are compared and combined to better extract small topographic linear features from high resolution digital aerial imagery.

II. METHODS

A. Line detection using LINDA

The main method used for line detection in LINDA is called gradient direction profile analysis (GDPA). The GDPA algorithm was proposed and applied for road extraction from satellite remotely sensed data (Wang et al., 1992; Wang and Liu, 1994; Gong and Wang, 1997; Wang and Zhang, 2000). Although the GDPA algorithm performs relatively well for road extraction from certain satellite images within urban areas, it has not been tested for extracting other types of small linear features from very high resolution (for example, 20-25 cm) aerial orthophotos.
We obtain an initial linear feature map after performing the Gradient Direction Profile Analysis. Since linear features should be continuous and relatively long, smaller areas and individual pixels are considered as noise. To remove such noise, a Connected Component Labeling and Filtering (CCLF) algorithm is applied. When the user specifies the size of the areas to be removed, determined by the number of pixels, the program will then remove all the connected components with areas less than the given size. Therefore small non-connected areas are removed. Next, a thinning algorithm is utilized to obtain lines which are only one pixel in width. After thinning, a pruning process is performed to remove remaining barbs shorter than a user-defined threshold. As a result, the final linear feature map is generated.

B. Edge detection using Wavelets

For a given image, the wavelet transform of the image is proportional to the gradient of the image after smoothing. Some specific kinds of edges, such as sharp edges or nearly sharp edges which appear at some linear feature edges, can be characterized by comparing the magnitudes of their gradients under wavelet transforms at different dilation scales of the same wavelet (Chen et al. 2004).

This method was first developed to extract road networks from high resolution air photos and IKONOS satellite data (Chen et al. 2004). It is based on selecting wavelets with proper supports. Ideally the brightness contrast across the linear feature edges should be strong. This kind of edges can be easily characterized by multi-scale wavelet transforms. In addition, by choosing wavelets with proper supports, linear features with apparent difference in width can be separated. Thus, extracting linear features from high-resolution remote sensing images using wavelets becomes possible.

The 2-D wavelet transform is performed on the aerial images by computing the modulus of the wavelet transform at a suitable scale (S), i.e., with a proper width of support. Here the quadratic function is chosen. The wavelet transformed edges of the linear features with a width close to the given scale (S) appear brighter and edges of some other smaller features are weakened. Next local maxima of the wavelet modulus were detected. A proper threshold (TD) is then applied to remove the lowered values which correspond to the undesirable objects. After thresholding, information of the edges is retained and other dim objects are gone. Basically, the linear features are represented by parallel edges.

C. Integration of Wavelets and LINDA

Based on our experiments, LINDA is suitable to extract thin lines from the aerial photographs and the Wavelets are more suitable to detect thicker lines or larger linear features. However the results from the Wavelet method are not thin lines. By combining the thinning and pruning algorithms in LINDA, some post-processing may be performed to further improve the linear feature extraction results from the Wavelets. Conversely, in order to eventually convert the linear feature maps into vector GIS format, the lines should be one pixel in width. A thinning algorithm in LINDA (Wang, 1993) may be applied to produce lines which are only one pixel in width. After thinning, a pruning process may be performed to remove remaining small branches shorter than a user-defined value.

III. LINEAR FEATURE DETECTION RESULTS

More than 20 sub-images were selected to test the suitability of Wavelets and/or LINDA for extracting small linear features from high resolution aerial photographs, from the original 15 orthophoto frames. Each orthophoto represents a ground area of 1000 m by 1000 m. The spatial resolutions are very high (20-25cm). There are various linear features at both study sites. The linear features evaluated in this study include garden boundaries (fences/hedgerows/walls), rural fences, field boundaries, forest ridges/hedges, small unsurfaced roads and power lines.

The colour photos were first separated into three separate bands; red-band1, green-band2 and blue-band3. From visual evaluation, the band 3 (blue) images showed the linear features more clearly. However when we compare the linear feature extraction results from Bands 1, 2 and 3, we did not find much difference in terms of the selection of parameters during the extraction or the performance of the extraction. Therefore band 3 images were used in the linear feature extraction. For the Wavelets method, or LINDA, or both Wavelets and LINDA, different combinations of parameters/processes were experimented on each sub image in order to select the most proper parameters and to achieve the best linear feature detection results.

From visual examination of the selected test images described above, it can be seen that linear feature appearances are quite different from scene to scene. The effectiveness of linear feature extraction was compared with the original images in the corresponding large scale map data.

A. Comparison of Wavelets and LINDA for feature extraction

1) Garden boundaries:

For garden boundary extraction from the high resolution aerial orthophotos, two subscenes were selected. Both subsences are located in high density urban residential areas. The purpose is to detect backyard garden boundaries comprising fences, hedgerows or walls. Those are extremely difficult scenes for linear feature detection, since they are very complex high density urban scenes, with various other line-like features such as the edges of roofs, buildings, building shadows, cars, trees and roads. The results using LINDA or Wavelets alone are not satisfactory.

2) Rural fences:
For the rural fence examples, two scenes were selected. The fences were extracted fairly well for both scenes using either LINDA or Wavelets. The fences were extracted and no other features were extracted. This may be because that the fence in this scene has good contrast with its background and there are few similar width linear features in this scene. The fence is also showing as a thin line. Different thresholds were tried in the noise removal stage using the CCLF algorithm. When the filter size was too large, most of the noise could be removed, but at the same time, parts of the fence would also be removed. If the filter size was small then there were commission errors in the result, especially in the forested areas. Using the Wavelets method edges were extracted neatly. However it could not separate fences from other features such as buildings and roads. From this experiment, LINDA extracted the fences better than the Wavelet method.

3) Field boundaries:

Field boundaries in many cases are not digital ridges or valleys but edges. They are usually easy to identify using multispectral classification. However, some field boundaries are not very obvious edges, they are line-like. Most parts of the field boundaries were extracted satisfactorily using both LINDA and Wavelets, considering the relatively low contrast of the lines from the background. Although most parts of the boundaries were detected, there were still some locations of disconnection. The Wavelets method performed a little better in this case.

4) Field boundaries and Forest ridges/hedges:

A sub-image was used for testing the LINDA system for detection of forest ridges/hedges. It contains the entire field and some forest lines. The result of LINDA showed the forest line well but most of the field boundaries were not detected. The Wavelets method performed extremely well, in that both the field boundaries and the forest ridges were extracted correctly.

5) Unsurfaced roads:

Road detection has been of great interest in the past years. Many algorithms were developed to extract roads from a variety of remotely sensed data. In this project, major roads or paved roads are not the major concern since there are other methods that can be used for such road mapping. In this study, only small unsurfaced roads are considered.

The results of unsurfaced roads vary greatly from scene to scene. Although there were some texture/noise in the original sub image, they were filtered out during the process. Both LINDA and the Wavelets methods produced an excellent result for this subscene. The difference is that LINDA extracted road centerlines and Wavelets extracted road edges. Depending on what information is needed in a GIS database, LINDA or Wavelets may be chosen for this type of feature extraction.

B. Wavelets with Post-processing using LINDA

LINDA was used to further improve the wavelet transform results. After the Wavelet transform the edges/lines are still not one pixel thin. The thinning algorithm in LINDA helped to produce thin lines with only one pixel in width. Although not perfect, by combining the two together, we obtained much better results.

C. Multiple feature extraction from larger scenes

The above testing was done using small sub-scenes selected from the air photos. Two questions arise: (1) Can we apply the parameters in LINDA or Wavelets trained on these small subareas to larger scenes? (2) Can we detect different linear features separately in the same scene using different sets of parameters? To answer these questions, two larger scenes were selected to extract multiple linear features separately using LINDA, Wavelets or their combination. We obtained some very interesting results.

We have applied the parameters in LINDA or Wavelets trained on the small subareas to larger scenes. By using multiple scales and different thresholds/parameters, we were able to detect different linear features in the same scene separately using different sets of parameters.

IV. CONCLUSIONS

The effectiveness of LINDA, Wavelets and the combination of both was tested for small linear feature extraction from high resolution aerial orthophotos. The linear feature extraction results were compared with the original images and the existing large scale digital map data. Our findings are as follows.

1. The LINDA system is suitable to extract thinner linear features, in which case, single centre lines are required. While the Wavelet transform based method is suitable to extract thicker lines and edges. For wider linear features, Wavelets method produces double parallel lines.

2. The same linear feature detection algorithm does not have universal applicability to extract different small linear features from the high resolution aerial photographs. The effectiveness and the degree of difficulty of line extraction greatly depend on the nature of the data, especially the complexity of the scene and the background environment contrast with the linear features.

3. The best line detection results from LINDA were achieved for rural fences and some unsurfaced roads. The best results from Wavelets method were achieved for unsurfaced roads and field boundaries.

4. The worst linear feature detection results were for power lines and roads under dense forest covers. Some linear features may be impossible to detect automatically.

5. In general, the post-processing using the thinning algorithm in LINDA after the Wavelet transform
improved the final products and since the lines are with one pixel in width, they are easily converted to a vector based GIS.

6. By using multiple scale linear feature extraction, both LINDA and Wavelets can be used to separate different linear feature types, such as roads, fences and vacation houses. Each feature type may be extracted and recorded into a separate GIS layer.

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REFERENCES


Gong, P. and J. Wang, 1997, Road network extraction from high resolution airborne digital camera data, Geographic Information Sciences, 3(1-2): 51-59.


