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EXTRACTION OF CURVILINEAR FEATURES IN HIGH-RESOLUTION MULTISPECTRAL SATELLITE IMAGES

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ABSTRACT: Satellite imagery provides an effective aid to city planning. From a high-resolution spatial image, useful information such as road networks may be extracted readily. In this work we study a method to automate the extraction of curvilinear objects such as roads and canals from the very-high resolution multi-spectral IKONOS satellite imageries. Curvilinear feature extraction is composed of two steps: detection and connection. The two steps can be modular but they are not independent. The first step of work has been reported in (Hui, Liew and Kwoh 2001). In this paper, we present some of our exploration on the linking-up of the detected features with the idea of perceptual organization.

1. INTRODUCTION

Curvilinear features, such as roads, canals, and rivers, are of interest particularly to city-planners. Therefore, plenty of effort has gone into the study of curvilinear features in the last few decades. Techniques have been developed to extract curvilinear features in optical images of different resolutions and colour contents. We surveyed many existing works and developed an integrated technique to extract curvilinear features from high to very-high resolution multi-spectral images. Multi-spectral images generally are images with more than one band. However where there are more than 3 bands, a subset of 3 bands is usually chosen for visualization and for processing. The main feature of this technique is that it tackles colour information using the HSI scheme rather than the RGB scheme commonly used.

The technique we developed can be considered in 2 stages. The first stage is to detect and locate the feature points. A curvilinear feature is one that has the intensity profile of a ridge or a valley. Such points can be located pretty well with the differential geometric technique. The method to extend this technique to multi-spectral images has been discussed in (Hui, Liew and Kwoh 2001). The outline of the first stage of work is given by the flowchart of Figure 1.

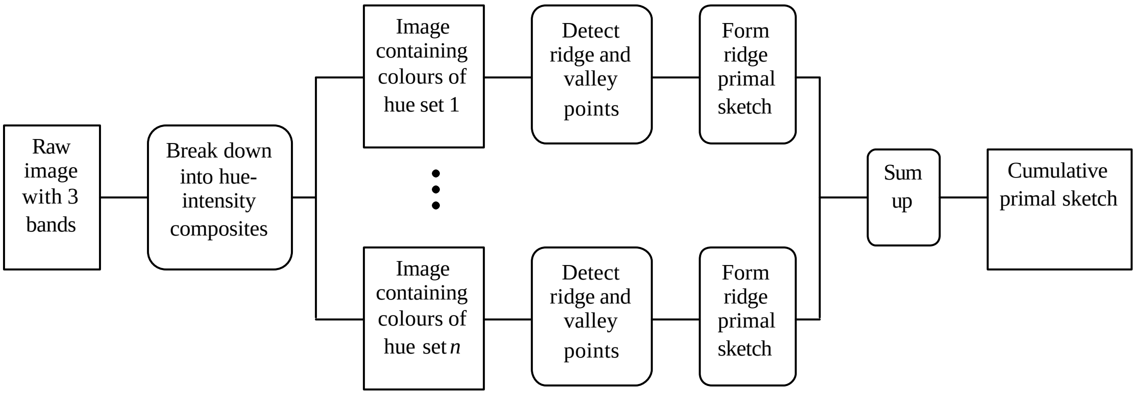


Figure 1 Process of curvilinear feature extraction for multi-spectral images

We shall not elaborate the technique of stage 1 here. In this paper we shall discuss the second stage of the work, namely to link up these ridges in the cumulative primal sketch, which models the shapes of the ridges of various colours, to form lines. To this end, we explored the idea of perceptual organization, which was first proposed by Montesinos and Blanc (Montesinos and Blanc June 1996). Their method favours the growth of lines of strong curvatures. We reconsidered the paradigm for features that tend to be linear or only mildly curved. Our approach is still at a developing stage, and we will report some preliminary results here.

Perceptual organization is based mainly on two classical assumptions—hierarchical organization and spatial continuity. By the first assumption, visual information is organized hierarchically. At the lowest level, the tokens of vision are individual points in the 2D space. The attributes of these points are their intensities and colours. At a higher level, the grouping of the spatial points forms spatial patterns. Then, at an even higher level, the collection of these spatial patterns forms spatial structures. The second assumption is that we have a sense of spatial continuity when we perceive structures from an arrangement of smaller visual tokens, (Marr 1982). For example, the arrangement of the black balls in Figure 2 causes us to perceive that they form a circle although the black balls are not connected to one another. Spatially the circle is perceived as a continuous structure even over the gaps in between adjacent black balls. In another example of Figure 2, despite that there exists a small gap between the two line segments, we are able to perceive that the two segments are parts of a continuous line. This ability to develop structures from smaller tokens, bridging the gaps among the fragments, is what the computational paradigm called perceptual organization attempts to model.

Figure 2 Both the perceptions of a circle from the black balls (left) and of a continuous line from two segments (right) illustrate "spatial continuity".

2. METHODOLOGY

2.1 The functions modeling the growth of connection

The perceptual organization paradigm is constructed by iterating the functions that model the growth of connection. There are 2 such functions: the strength of support, and the strength of connection. By the strength of support, the thing being modeled is the influence received by a pixel from its neighbour. All pixels receive some influence from each of the neighbours surrounding them. Each pixel *p* that is not on the boundary has 8 neighbours, thus there are 8 sources of the strength of support for *p*. The strength of connection, on the other hand, models the strength of a possible link that passes through a pixel. As such, the strength of connection involves a pixel and 2 of its neighbours. For a pixel *p* that has 8 neighbours, there will be 28 (=8×7/2) possible links that pass through *p*, and each such possible link has its own strength of connection. These two functions are mutually dependent.

Strength of support: Let *p* be a pixel in the primal sketch, then the strength of support from its neighbour *q*, at the *i*th iteration, denoted by F_{pq}^{i}, is

$$F_{pq}^{i} = \begin{cases} \dfrac{R_q^1}{d(p,q)} & \text{at initialization,} \\ \dfrac{R_q^{i-1}}{d(p,q)} + w_{pq}^{i}\,\dfrac{R_q^{i}}{d(p,q)} & \text{at each subsequent iteration } i > 1. \end{cases} \qquad \textbf{Eq 1}$$

where *q* is any one of the 8 neighbours of *p*, R_q^i is the primal sketch value of pixel *q* at the *i*th iteration, and *d(p,q)* is the Euclidean distance between the two pixels *p* and *q*. The parameter w_{pq}^{i} is a weighting factor such that its value is one if *p* lies on the anticipated direction that the curvature of the ridge passing through *q* will grow. If *p-q* deviates from this path, then the weight is reduced according to the angle α which measures how far the *p* deviates from the anticipated direction if the course *p-q* is to be pursued (see Figure 3).

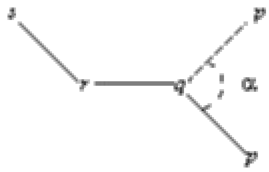


Figure 3 Connection is favoured along the direction that follows the local curvature of the link

Strength of connection: To find the anticipated ridge that will pass through q we need to consider all the strengths of connection, at q, that contain q-p. The strength of connection, C^i_{jpk}, where i is the iteration number, j and k (with $j \neq k$) are 2 neighbours of p is defined as

$$C^i_{jpk} = \left(F^i_{jp} + F^i_{pk}\right) u_{jpk}, \qquad \textbf{Eq 2}$$

where u_{jpk} is a weighting factor depending on the angle $\angle jpk$ that encourages connections having low curvatures.

2.2 Iterative change of the perceived primal sketch surface

The state of the perception of the primal sketch surface changes as the strengths of support affect the strengths of connection at every pixel. After the establishment of support and connection among pixel, the state of the perceived primal sketch surface is also updated based on the strength of connection. The ridge is grown along the direction of strongest connection. The perceived primal sketch changes its shape as ridges are picked up. A point, which is in a ridge, is reinforced by those of its neighbours that are in the same ridge. At the same time, the point inhibits all other neighbours, that is, those that are in the same ridge.

The iterative process is shown in the flowchart of Figure 4:

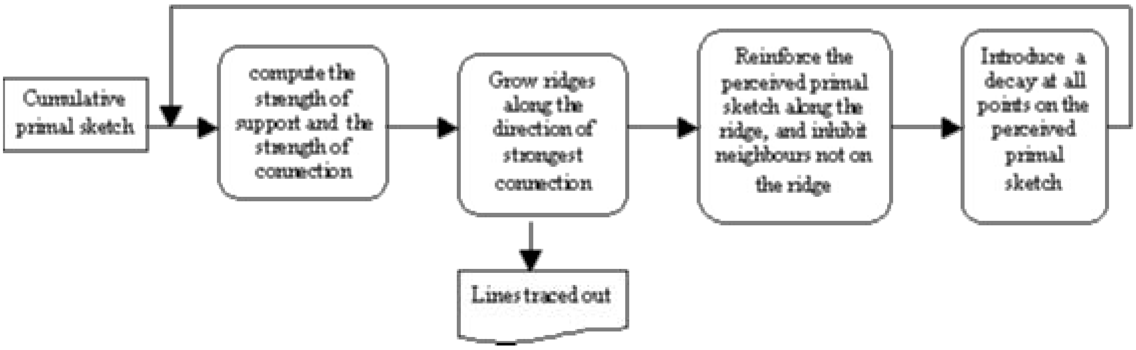


Figure 4 The iterative process of perceptual organization

3. EXPERIMENTS

We tested this technique with the cumulative primal sketches of some sub-images of the 1-meter pan-sharpened IKONOS data. In Figure 6, we present 3 sets of details of the results. This includes the original sub-images, the cumulative primal sketches obtained from stage 1, and the ridges picked up from the cumulative primal sketch after the first, the second and the third iterations respectively.

For this set of data, we observed the following:

1. Majority of the ridges are picked up at the first iteration.
2. There is still significant change in the ridges picked up, between the first and the second iteration. After the second iteration, the ridges do not change much.
3. This method distinctively favours the connection of broken straight ridges. However, when more ridges are picked up, more of them are false ridges. When we examine the false ridges, we find that they tend to come from noises that already exist in the cumulative primal sketch.

We have observed that, at each iteration, there are some changes in the ridges picked up. However, some of these changes are undesirable. In some cases, false ridges may be picked up. In others, ridges that should be distinct are connected. Many of the false ridges come from noises in the cumulative primal sketch. Currently, colour information is used only in the detection step (that is stage 1). The cumulative primal sketch models the shapes of the ridges, but does not include the colour information of each ridge. Therefore, we cannot make use of the colour to help us in linking up the ridges in the second stage.

4. CONCLUSION

We have developed an alternative paradigm of perceptual organization for the extraction of curvilinear features in multi-spectral images. However, we are yet to quantify the performance of this technique. The future direction of this work is towards including the colour information of the ridges not only in the detection step but also to assist the linking-up process as well.

5. REFERENCES

Hui, A., Liew, S. C., and Kwoh, L. K., 2001. Extraction of linear features in multi-spectral imagery. In the Proceedings of the International Geoscience and Remote Sensing Symposium (IGARSS) 2001, July 2001, Sydney, Australia.
Marr, D., 1982. Vision, W. H. Freeman and Company, pp 44-50.
Montesinos, P. and Blanc H. V., June 1996. Perceptual Grouping of Continuation: Application for Satellite Images EERIE/LERI technical report.

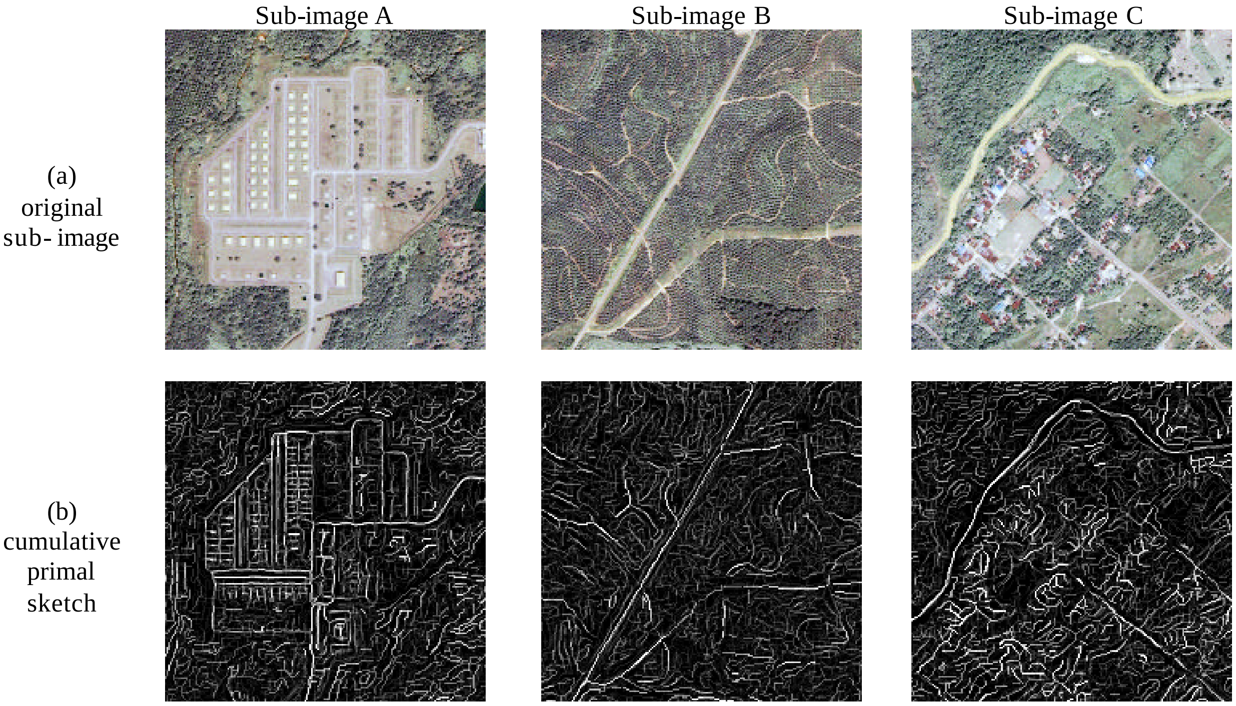
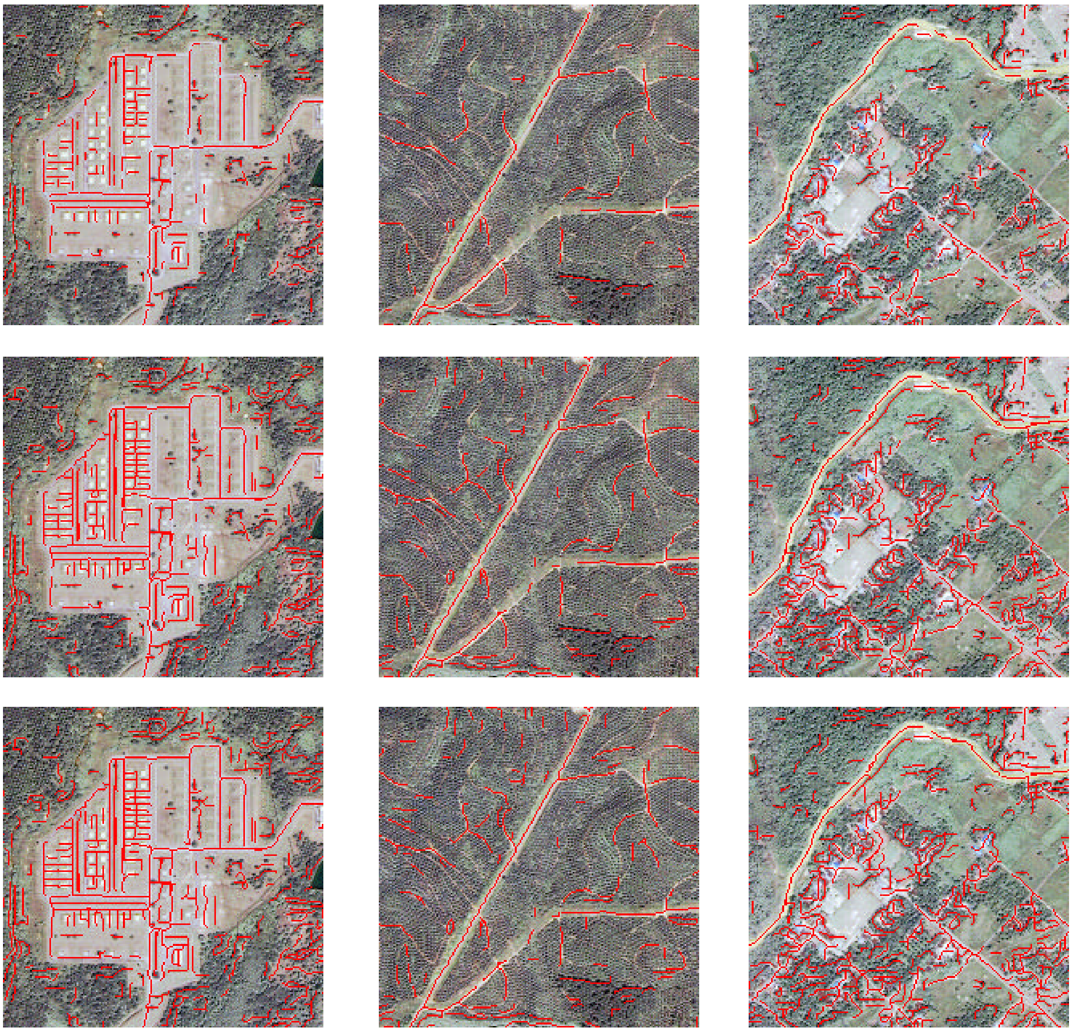


Figure 5 The result of perceptual organization on the sub-image of an IKONOS scene (continue on the next page)



(c)
ridges
after
iteration 1

(d)
ridges
after
iteration 2

(e)
ridges
after
iteration 3

Figure 6 (continued)