ON THE USE OF FRACTALS FOR INTERPRETING AERIAL RECONNAISSANCE IMAGES

Brian E. COOPER and Darrel L. CHENOWETH

University of Louisville
Louisville, Kentucky USA

Abstract. The performance of map matching navigation systems employing reference maps obtained from aerial reconnaissance imagery is the motivation for this paper. In particular we look at the problem of selecting scene locations that contain stable features. Since cultural features are often very stable, the cultural content of an image is useful information for the scene analyst. A fractal-based technique is demonstrated which may be used to extract the cultural content of a candidate reference map scene.

Résumé. L'objet de cette dissertation est l'évaluation du fonctionnement des systèmes de navigation pour l'appariement des cartes, employant des cartes créées des images de reconnaissance aérienne. En particulier on souligne l'importance de la sélection des localisations de scène qui ont des caractéristiques stables. Comme les caractéristiques culturelles sont souvent très stables, le contenu culturel d'une image est très utile pour un analyste de scène. On va décrire une technique de base "fractal" que l'on peut employer pour extraire le contenu culturel pour une scène de carte particulière possible.

1. INTRODUCTION

One of the concerns in using map matching navigation systems is the problem of the delay between when the navigation map is created and when it is used. During this time period the scene features may change, i.e., the features may be unstable.

In choosing reference map locations, the scene analyst must be very selective in choosing scenes that have a relatively high content of stable scene features. There are several general guidelines that may be used. For example, seasonal variations can cause foliage features to change due to changes in chlorophyll content and leaf loss, while diurnal variations can produce shadow instabilities. Therefore, one usually tries to avoid using scenes that have a high proportion of deciduous trees or a high concentration of tall shadow casting objects. These are but a few of a number of guidelines that are used.

In general, however, there is no single analysis tool available to the scene analyst for extracting the stable feature content from a candidate reference image. He must rely on experience and a collection of heuristics that guide him in selecting scenes that work well as reference maps. In this paper we will take a small step in that direction by proposing an analysis tool that can be used to measure the cultural feature content of a scene. Since many cultural features features, e. g. roads, buildings, etc., in scenes are stable, the goal is to extract these types of features and give this information to the scene analyst to use as a partial indicator of stable feature content in a candidate reference map scene.

The technique is based on the fact that natural scene features have been shown to fit fractal models, at least over a limited range of scales, while cultural features do not generally fit a fractal model, except in the limiting case of a perfectly smooth cultural scene feature having a constant gray level over the area of interest. We will look at a potential method for determining the *fractalness* of scene features and demonstrate its efficacy on two sample urban images obtained in April and in October.

2. FRACTIONAL BROWNIAN MOTION

A very useful model for random fractals found in natural scenes is the fractional Brownian motion model of Mandelbrot [1]. Fractional Brownian motion is characterized spatially by the the nonlinear scaling property known as self-affinity. Mathematically it can be stated as

$$|\Delta V_{|\Delta \mathbf{x}|}| = K \, |\Delta \mathbf{x}|^{H} \qquad (1)$$

where ΔV is the variation in intensity of two image pixels, $\Delta \mathbf{x}$ is the distance between the pixels and K is a proportionality constant. H is known as the Hausdorff dimension and is related to the fractal dimension D by

$$D = G + 1 - H \qquad (2)$$

$$0 < H < 1$$

where G is the topological dimension. G is 2 for images.

3. ESTIMATING THE FRACTALNESS OF SCENE FEATURES USING THE NONLINEAR SCALING PROPERTY

Equation (1) provides a convenient way to estimate the fractalness of a scene feature. If H is estimated and found to be constant over a range of $\Delta \mathbf{x}$ then we can infer that the feature being considered is fractal in nature, with a fractal dimension of $3 - H$. H can be estimated locally in a candidate reference scene over a range of displacements by using

$$log(E[\,|\Delta V_{|\Delta \mathbf{x}|}|\,]) = log(K) + H \log(|\Delta \mathbf{x}|) \qquad (3)$$

in a small window centered at the pixel of interest, where E[ ] denotes statistical expectation. The window should be large enough to contain a good sampling of the range of pixel displacements. Linear regression analysis may be applied to (3) to determine the values $\overline{H}$ and $\overline{K}$ that provide the best fit to the estimated data. The estimated variation $|\Delta \overline{V}|$ may be computed using (1) as

$$|\Delta \overline{V}_{|\Delta \mathbf{x}|}| = \overline{K} \, |\Delta \mathbf{x}|^{\overline{H}} \qquad (4)$$

Furthermore, the RMS error between the estimated variation in intensity $|\Delta \overline{V}|$ and the individual values of $E[|\Delta V|]$ measured at various fixed displacements within the window provides one with a metric for judging the fractalness of the data in the window. A good fit over a sufficiently wide range of displacements $\Delta \mathbf{x}$ will produce a small RMS fractal error, which indicates the portion of the scene feature in the window is highly fractal in nature (in this study we used a range of five different displacements in a 5x5 window). Conversely, if the RMS error is large, a non-fractal feature is implied. Previous work by Stein [2] also supports this conclusion.

4. AN EXAMPLE

The following example is given to demonstrate the utility of the previously described method for measuring the fractalness of features in aerial images. Two images of an urban scene were tested. The scenes contain predominantly cultural features, but there are some natural features also included in the scenes in the form of deciduous trees. The two 243x216 spatial resolution scenes were obtained at different times of the year in 1988. Figure 1 illustrates the urban scene in April 1988 and again in October 1988. Note the changes in the deciduous trees and the related shadows. Figure 2 illustrates the RMS fractal error metric obtained by attempting to fit a fractal dimension to 5x5 windows in the two scenes using the technique described in Section 3. The lighter gray levels correspond to image features that do not fit a fractal model well, while the darker areas correspond to low RMS fractal error, and consequently a good fit to the fractal model over the range of spatial differences contained in the 5x5 window.

This example illustrates another interesting point concerning fractal models of natural scenes. The two images in Figure 1 are digitized in the range 0 to 255, and one can clearly see the differences in the images induced by the illumination of the scene. The October scene has a much higher average gray level and variance than the April scene (mean 97 and variance 1348 for October versus mean 54 and variance 815 for April). These differences are principally due to the difference in illumination conditions on the days when the two images were obtained. If we compare the fractal error images, which are also scaled in the range of 0 to 255, we find that not only are the stable features enhanced, but the statistics for the two scenes are more consistent. Specifically, in Figure 2 the mean is 31 and the variance is 487 for October, versus a mean of 24 and variance 448 for the April scene. The consistency in contrast between the two fractal error images results because we are comparing textures of the two images, and texture is relatively independent of illumination.

5. CONCLUDING REMARKS

In this paper we have considered a fractional Brownian motion model that is commonly used to model natural image features, and we have used it to examine scene features occurring in aerial reconnaissance imagery. Although this work is very preliminary, it shows some promise in providing a technique for discriminating between natural scene features and cultural features.

Natural features tend to be fractal-like, while man-made features tend to have a lower degree of fractalness. Furthermore, cultural features tend to be more stable than natural features in the context of the map matching navigation problem. This is quite evident in comparing the fractal error images from April and October in Figure 2. The gray level images from the two scenes appear to vary significantly due to the changes of the deciduous trees. However, since the fractal error image ignores natural features we enhance only the more stable cultural areas of the scene. Thus, the method described in this paper may provide the scene analyst with another tool for determining the suitability of candidate scenes for preparing reference maps.

REFERENCES

[1] Mandelbrot, B. B., *The Fractal Geometry of Nature,* W. H. Freeman and Co., New York, 1982.

[2] Stein, M. C., "Fractal image models and object detection," *Visual Communication and Image Processing II*, Hsing, T. R. ed., Proc SPIE 845, pp293-300,1987.

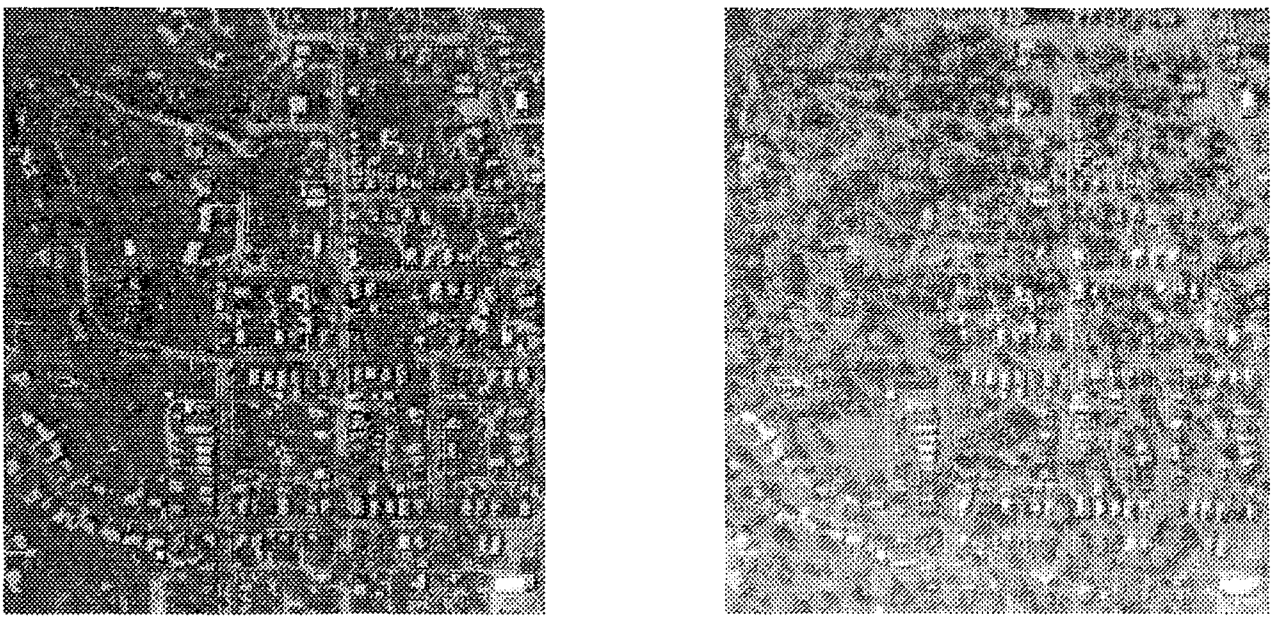

Figure 1. April (left) and October (right) urban scenes

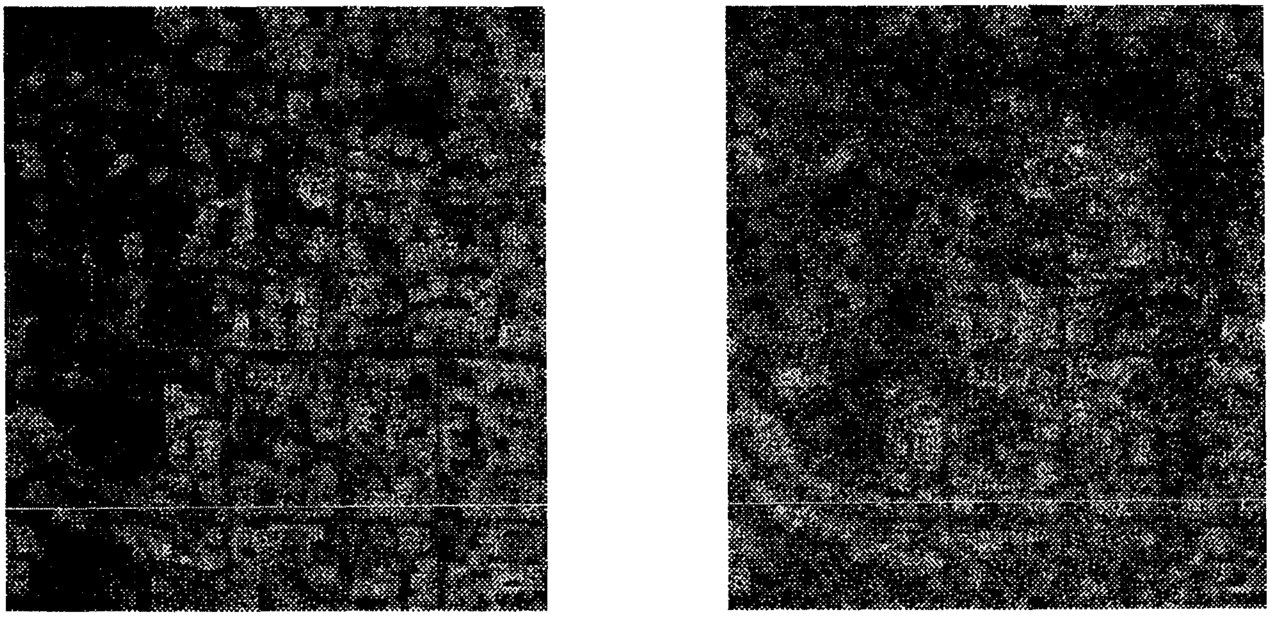

Figure 2. RMS fractal error for scenes in Figure 1