CONNECTED ATTRIBUTE FILTERING BASED ON CONTOUR SMOOTHNESS

G. K. Ouzounis\(^1\), E. R. Urbach\(^2\), M. H. F. Wilkinson \(^3\)

\(^1\) Digital Globe Inc.,
1601 Dry Creek Drive, Suite 260, Longmont, CO 80503, USA.
georgios.ouzounis@digitalglobe.com

\(^2\) University of Groningen PO Box 83, Croydon, NSW 2132, Australia,
erikurbach@yahoo.com

\(^3\) Johann Bernoulli Institute for Mathematics and Computer Science,
University of Groningen, PO Box 407, 9700 AK Groningen, Netherlands.
m.h.f.wilkinson@rug.nl

A new attribute measuring the contour smoothness of 2-D objects is presented in the context of morphological attribute filtering. The attribute is based on the ratio of circularity to non-compactness and has a maximum of 1 for a perfect circle. It decreases as the object boundary becomes irregular. Computation on hierarchical image representation structures relies on five auxiliary data members and is rapid. Contour smoothness is a suitable descriptor for detecting and discriminating man-made structures from other image features. An example is demonstrated on a very-high-resolution satellite image using connected pattern spectra and the switchboard platform.

Introduction

In image analysis, the detection of man-made structures remains a challenge due to the limited descriptors available to distinguish them from other image features. Linearity is defined as the ratio between the principal axes of image components from its PCA analysis. It can distinguish artificial structures from others but can easily be misled for example by a row of adjacent trees, which has a high linearity measure too. Corners \([1,2]\) are good indicators of artificial structures but do not comply with the framework of connected image analysis and moreover, are very sensitive to the image radiometry. Other shape-based descriptors like rectangularity or triangularity \([3]\) are derived from moments of inertia and describe best fitted shapes rather than actual component attributes, i.e. suitable for post-processing.

In this paper a new component attribute is proposed measuring directly the smoothness of connected component contours. The proposed attribute is utilized by morphological connected attribute filters \([4]\) that are discussed next.

Following this, the definition and derivation of contour smoothness is given along with an experiment in detecting man-made structures form very high resolution satellite imagery. A brief discussion and conclusions are given at the end of the paper.

Image content organization

The organization of the image information content into connected regions or components is a well-established strategy in image analysis \([5]\) allowing for efficient and edge preserving processing. Attribute filters \([4]\) are morphological operators deciding on accepting or rejecting connected components based on some attribute measure. They find use in a wide range of applications \([6]\) and can be implemented efficiently on hierarchical image representation structures like the Max-Tree \([7]\) and the Alpha-Tree \([8]\), or directly based on the Union-Find algorithm \([9]\) or other similar component labeling schemes. An important tool based on attribute filters is the pattern spectrum \([10]\) which is a multi-dimensional attribute histogram or feature space. The switchboard platform \([11]\) is a wrapper of the pattern spectrum allowing for real-
time interaction with the image space via the tree data-structure used for image representation.

**Contour smoothness**

The proposed measure of contour smoothness is a ratio of two geometric descriptors; the circularity and non-compactness of a connected component. As the contour of a connected component becomes rougher the circularity reduces while the non-compactness increases thus the ratio decreases along. Contour smoothness has a maximum of 1 for a circle.

The circularity of a component $C$ is a normalized measure of compactness:

\[\text{circularity} = \frac{P^2}{4\pi A},\]  
\[(1)\]

in which $P$ is the perimeter and $A$ is the area (pixel count) of $C$. Circularity has a maximum of 1 for a perfect circle and reduces as the shape deviates from a circle.

The non-compactness is a scale invariant measure given by:

\[\text{non-compactness} = \frac{2\pi I}{A^2},\]  
\[(2)\]

in which $I$ is the moment of inertia of a connected component given by:

\[I = \sum_c (x - \bar{x})^2 (y - \bar{y})^2\]  
\[(3)\]

The terms $x$, $y$ are pixel coordinates and $(\bar{x}, \bar{y})$ are the coordinates of the component’s centroid:

\[\bar{x} = \frac{1}{A} \sum_c x\quad \text{and}\quad \bar{y} = \frac{1}{A} \sum_c y.\]  
\[(4)\]

The term $2\pi$ in (2) is to normalize the attribute to a minimum value of 1 for a perfect circle. To improve scale invariance of (3) a further term is added that accounts for the pixel shape; pixels are assumed to be unit squares, each with a moment of inertia equal to:

\[\int_{-0.5}^{0.5} \int_{-0.5}^{0.5} (x^2 + y^2) \, dy \, dx = \frac{1}{6}\]  
\[(5)\]

as in [12]. Expanding (3) further and correcting for the square shape of pixels we obtain:

\[I = \sum_c x^2 + \sum_c y^2 - \frac{\left(\sum_c x\right)^2}{A} - \frac{\left(\sum_c y\right)^2}{A}\]  
\[(6)\]

\[+ \frac{A}{6}\]

**Definition.** The contour smoothness $cs$ of a connected component is given by:

\[cs = \frac{\frac{P^2}{2\pi I}}{\frac{A^2}{8\pi^2 I}} = \frac{A P^2}{8\pi^2 I}.\]  
\[(7)\]

The contour smoothness measure is scale invariant but sensitive to the definition of the perimeter measure $P$. A simple definition for $P$ is the count of all pixels of a connected component that border (4-way adjacency) a pixel of different intensity. Perimeter measures like the city-block or contour pixel counts based on 8-way adjacency require further corrections in (7). The computation of (7) can be done incrementally by the aid of 5 auxiliary data members; pixel count, perimeter pixel count, sum of $x$, sum of $y$, and sum of squares ($x^2 \Box y^2$). The same pool of auxiliary data allows for a wider range of attributes to be computed and offers a robust connected-component characterization.

**Experiments**

The objective of the experiment presented in this section is to extract man-made structures from satellite imagery that are characterized by a varying degree of size and contour smoothness. To exploit the image information content efficiently a Max-Tree structure is computed from the input image shown in Fig.1.(a). All auxiliary data needed for the computation of component attributes are collected during the construction of the tree.

Once the tree is constructed, a connected-pattern spectrum [10,14] is computed by a simple pass through the structure. This is a
Fig. 1. (a) A sample panchromatic image tile of an urban area by the WorldView 2 sensor (©DigitalGlobe Inc.).
(b) Image segmentation based on contour smoothness using the switchboard platform on the pattern spectrum in (c); selected switches are shown in (d).

normalized attribute histogram obtained by measuring the contribution of all connected components represented by the tree as a function of their attribute value, to the respective bins. Fig. 1(c) shows the connected pattern spectrum of (a), in which the x-axis corresponds to the size attribute (logarithmic mapping) and the y-axis to the contour smoothness attribute (logarithmic mapping). Each bin intensity is a normalized value [0-255] of the area of all components satisfying the bin extrema conditions multiplied by each
component’s lifetime. The origin is at the top left of each plot; the first bin corresponds to all components having the smallest area and smallest contour roughness (inverse of smoothness) in the decomposition. The pattern spectrum is interfaced by the switchboard platform [11] that allows for interactive and real time image segmentation. Fig.1.(b) and Fig.2.(a),(b) show segmentation instances based on the respective switch selections marked with red on each pattern spectrum.

Discussion

The previous experiment demonstrated that contour smoothness along with size, offers a good approximation of man-made structures in very high resolution satellite imagery. That is due to the fact that most built-up appears with smooth contours by contrast to non-man-made objects. Thresholds on contour smoothness are subject to the image information content, and as shown in Fig.2.(b) beyond a certain value range, segmented objects become meaningless.

Contour smoothness is a non-increasing attribute [4] and so is the respective attribute filter. For the latter, when computed on a hierarchical image representation structure, special filtering rules apply. Contour smoothness filters implemented on the Max-Tree [7] require the subtractive rule [10]; if implemented on the Alpha-Tree [8] they require the max-rule [8].

The formalization of contour smoothness as a function of five auxiliary data members, allows it to be computed incrementally during the tree construction or in a single pass through the image following tree construction. Typical timing for a panchromatic image with a raster size of 10,000×20,000 pixels is 2.83 s. on a 64bit Intel Core i7-2760QM CPU@2.40GHz machine with 4GB of RAM. Using the parallel algorithm in [13,14] this can be reduced to less than one second on four cores.

Conclusion

A new attribute measuring the contour smoothness of connected components was presented. Contour smoothness can be used to discriminate man-made structures from other image features and an example was demonstrated. Future work includes methods for automatic threshold selection based on connected component statistics.

References