third-order elliptic ladder filter has been synthesised. Simulation proposed method is expected to be useful in the synthesis of log-
results have also been given to verify the theoretical analysis. The domain ladder filters with or without transmission zeros.

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References


Fuzzy pattern spectrum as a texture descriptor

M. Ghadiali, J.C.H. Poon and W.C. Siu

Indexing terms: Texture (image processing), Fuzzy systems

The authors introduce a novel descriptor for texture classification, namely the fuzzy pattern spectrum (FPS). Essentially, the FPS is a novel extension of the traditional morphological pattern spectrum, the significant advantage being its effectiveness in quantifying spatial uncertainty in images. A texture classification experiment is discussed to show the usefulness of the FPS wherein a classification accuracy of 94% is achieved.

Introduction: Mathematical morphology is a powerful tool for shape and feature analysis and feature representation. Work [1] in this field has sought to augment the scope of traditional morphology using the tools of fuzzy sets, hence gaining an understanding of the 'spatial uncertainty' or 'fuzziness' in image features. Fuzzy mathematical morphology extends the intuitive notion of 'fitting' in traditional morphology, to the 'degree of fitting'.

In fuzzy mathematical morphology, the degree of subheading between the image and the structuring element needs to be determined. This is realised using an indicator function which is essentially a mapping from two fuzzy sets, the image A and structuring element B, to another fuzzy set (the degree of set inclusion). Based on this, the representation for fuzzy erosion [3], \( \mu_{E(A,B)}(x) \), is as follows:

\[
\mu_{E(A,B)}(x) = \inf \{1 + \mu_A(x) - \mu_B(x) \} \quad (1)
\]

\( \mu_A(x) \) and \( \mu_B(x) \) denote memberships of element \( x \) to the fuzzy sets A and B, respectively.

Texture classification using FPS: Multi-scaled morphological operations have been used to generate shape-size descriptors termed the pattern spectrum [3] or the peckurst [4]. The pattern spectrum can be considered to be analogous to the Fourier spectrum, the difference being that the first quantifies shape, whereas the latter quantifies the frequency distribution of the signal. Morphological operations are used to generate descriptors that determine up to what scale a given shape exists in an image. A structuring element B can generate a multi-scale family of structuring elements by dilating itself, thus:

\[
nB = B \oplus B \oplus B \cdots \oplus B \quad (n \text{ times}) \quad n = 0, 1, 2, \ldots \quad (2)
\]

A family of multi-scale erosions where B is the generator is denoted by

\[
X^{En} = [(X \ominus nB)] \quad (3)
\]

where \( X^n \) represents the erosion of image \( X \) by \( nB \).
The drawback of the traditional pattern spectra is their inability to deal with the fuzziness in terms of image gray levels. The images need to be binarised to determine the residues, and the resultant pattern spectra are highly sensitive to the thresholds in actual implementation. The fuzzy pattern spectra (FPS) alleviates this problem by dealing with gray level images directly, and quantifies the shape-size distributions in terms of fuzzy memberships.

For a discrete M-dimensional crisp function f, its fuzzy representation J can be obtained using a fuzzifier φ such that φ: R → [0, 1]. Thus, we have the fuzzification of the image f and structuring element b, as φ: f → J and φ: b → β, respectively, and Jβ denotes the result after fuzzy erosion by structuring element β. The FPS for a discrete M-dimension function J ∈ R^m is defined as

\[ P(n) = N_n / \text{Mes}(J) \]  

(4)

where \( n ∈ Z \), \( \text{Mes}(J) = \sum(x_j, x_k, x_m, x_n) \) and \( N_n \), the fuzzy erosion residue, thus,

\[ N_n = \text{Mes}(J_{α,β}) - \text{Mes}(J_{(n+1),β}) \]  

(5)

In practical implementation of the fuzzy pattern spectrum, we need to specify the α-cut which determines the value of \( N_α \). This presents a significant flexibility, since there is no dual parameter to \( N_α \) in crisp pattern spectra. Although the selection of \( α = 0 \) is heuristic, it is dependent on the actual number of erosions used. The value of \( α \) must however be > 0, since \( α = 0 \) is the image background.

Texture classification results: The application of the FPS for texture representation and classification is demonstrated using an unsupervised classification approach. Five texture sets (D4, D20, D64, D74 and D95) were scanned from the Brodatz album [4] at 300dpi to 256 gray level images with 256 × 256 pixel resolution.

The FPS for each image was calculated using 10 erosions (eqn. 1) by disk shaped isotropic structuring elements, the first being a disk of three pixels in diameter, and the rest obtained by iterative dilation of the initial structuring element alone. Eroded results for one prototype texture (D20) are shown in Fig. 1. The prototype set consisted of five images, the FPS of which are shown in Fig. 2a.

The test set comprised 50 unknown images, 10 from each texture set. The FPS of one such test set (texture D4) are shown in Fig. 2b. The distance between the FPS of each image in the test set and the five prototypes was calculated using the sum of absolute differences, and then classified based on the minimum distance criterion. The classification results are shown in Table 1. From the set of 50 test images, 47 were correctly classified and the average error margins (average of the distance between the classification result and correct texture) for wrongly classified textures were < 0.04. It is believed that these results could be improved using a larger number of erosions. The simulations were performed on a SparcStation2 (mem: 49152K em: SUNW, SunOS 7.1) and the user CPU times were ~60s to generate the FPS for each image.

### Table 1: Texture classifications results

<table>
<thead>
<tr>
<th>Texture type</th>
<th>Correct classification</th>
<th>Wrong classification</th>
<th>Average margin of error</th>
</tr>
</thead>
<tbody>
<tr>
<td>D4</td>
<td>10</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>D20</td>
<td>10</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>D64</td>
<td>8</td>
<td>2</td>
<td>0.03</td>
</tr>
<tr>
<td>D74</td>
<td>10</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>D95</td>
<td>9</td>
<td>1</td>
<td>0.02</td>
</tr>
</tbody>
</table>

Conclusion: This Letter presents the fuzzy pattern spectrum as a robust shape-size descriptor and demonstrates its ability to deal with inherent fuzziness in gray level images. We envisage that the FPS can be used in cataloguing texture databases, since it provides concise descriptors which can be matched easily, giving an efficient search and storage mechanism. The accuracy of descriptors can be enhanced by using fuzzy openings which yield finer spectra. The processing times for generating the FPS for textures are expected to be considerably improved using fast, optimised algorithms and parallel processing architectures.

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References


Image compression using bit-plane coding of wavelet coefficients

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Indexing terms: Wavelet transforms, Image coding, Data compression

The authors propose a new simple image coder based on a discrete wavelet transform (DWT). The DWT coefficients are coded in bit-planes. They use an improved version of the JBIG bi-level image compression method to code the DWT coefficients bit-planes. The experimental results are shown, both in distortion measurement and visual comparison, and are very promising.