Content Based Image Retrieval Using Curvelet Transform

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Outline

• Motivation
• Texture Features
• Curvelet Transform
• Experiments and Results
• Conclusions and Outlook
Content Based Image Retrieval

• How to organize and find images
• Search images based on content
Texture Features—What are they?

- **Higher level**
  - Contrast
  - Directionality
  - Regularity
  - Smoothness

- **Low level**
  - Edges
  - Repeating patterns
  - Variation frequency

- **Higher level texture features are difficult to define and obtain**
Texture Features—Approaches

• **Spatial Features**—sensitive to noise
  – Statistical: mean, variance, skewness, kurtosis, co-occurrence matrix, moments
  – Probabilistic: Markov models
  – Structural: regularity, directionality, roughness
  – Histogram: edge
  – Fractal: box counting

• **Spectral Features**—robust, so far the best
  – Wavelet
  – Gabor Filters
  – Curvelet
Wavelet

\[ \psi_{a_1, a_2, b_1, b_2}(x, y) = a_1^{-\frac{1}{2}} a_2^{-\frac{1}{2}} \psi \left( \frac{x-b_1}{a_1} \right) \psi \left( \frac{y-b_2}{a_2} \right) \]

- Where \( a_1, a_2 \) are wavelet scales at horizontal and vertical directions; \((b_1, b_2)\) is the wavelet location.
Wavelet Coefficients

- Wavelets are only applied at horizontal, vertical and diagonal directions
- However, textures are at various directions
Gabor Filters

- A Gabor filter is a Gaussian envelope modulated by a sinusoidal plane wave along the $x$-axis:

$$\psi(x, y) = \frac{1}{2\pi\sigma_x \sigma_y} \exp\left[-\frac{1}{2} \left( \frac{x^2}{\sigma_x^2} + \frac{y^2}{\sigma_y^2} \right)\right] \cdot \exp(j2\pi Wx)$$

- Where $\sigma_x$ and $\sigma_y$ are the standard deviations of the Gaussian envelop, $W$ is the modulation frequency for the filter.
Gabor Filter in 3D View
Gabor Filter Coefficients

- Capture texture features at various directions and scales.
- However, the spectra cover is not complete.
- Redundant info in filtered images.
Gabor Filters—Spectra

- The frequency responses of Gabor filters are also Gaussians.
- Due to the elimination of spectra overlap, ‘holes’ (black areas) are created in the spectra plane.
- This causes loss of significant spectral information.
Ridgelet

- Basically, curvelet transform extends the ridgelet transform to multiple scale analysis. Given an image function $f(x, y)$, the continuous ridgelet transform is given as:

$$
\mathcal{R}_f (a, b, \theta) = \int \int \psi_{a, b, \theta}(x, y) f(x, y) dx dy
$$

- Where $a > 0$ is the scale, $b \in \mathbb{R}$ is the translation and $\theta \in [0, 2\pi)$ is the orientation. The ridgelet is defined as:

$$
\psi_{a, b, \theta}(x, y) = a^{-\frac{1}{2}} \psi \left( \frac{x \cos \theta + y \sin \theta - b}{a} \right)
$$
Ridgelet vs Wavelet

- Ridgelet is similar to the 2-D wavelet except that the point parameters \( (b_1, b_2) \) are replaced by the line parameters \( (b, \theta) \). In other words, the two transforms are related by:
- Wavelet: \( \psi_{\text{scale, point-position}} \)
- Ridgelet: \( \psi_{\text{scale, line-position}} \)
Curvelets—Ridgelet Tuned to Various Directions and Scales

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Curvelet Spectra

• Compared with Gabor filters, the curvelet spectral plane is completely covered. There are no ‘holes’.
• The red wedge is the frequency response of curvelet at scale 4 and orientation 4.
Curvelet Coefficients

Curvelet subband at scale 6
Curvelet subbands at scale 5
Curvelet subbands at scale 4
Curvelet subbands at scale 3
Curvelet subbands at scale 2
Curvelet subband at scale 1
Curvelet Implementation—Computing
## Curvelet Implementation—Coefficients

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**4 level curvelet transform**

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<td>8</td>
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<td>16</td>
<td>1</td>
</tr>
</tbody>
</table>

**5 level curvelet transform**
Curvelet Features and Similarity

\[ E(a, \theta) = \sum_x \sum_y |\text{Curvelet}_{a\theta}(x, y)|, \quad a = 0, 1, \ldots, S - 1; \quad \theta = 0, 1, \ldots, \Theta - 1 \]

\[ \mu_{a\theta} = \frac{E(a, \theta)}{M \times N}, \quad M \times N \text{ is the image size} \]

\[ \sigma_{a\theta} = \frac{\sqrt{\sum_x \sum_y (|\text{Curvelet}_{a\theta}(x, y)| - \mu_{a\theta})^2}}{M \times N} \]

\[ D(Q, T) = \sum_a \sum_{\theta} \sqrt{(\mu_{a\theta}^Q - \mu_{a\theta}^T)^2 + (\sigma_{a\theta}^Q - \sigma_{a\theta}^T)^2} \]
Retrieval Experiments—Database

• The widely used standard Brodatz texture database is used in the test.
• It consists of 112 different categories of natural and man made texture images.
• Each category includes 16 similar images with 128x128 pixels.
• In total, the image database consists of 1,792 images from 112 categories.
Retrieval Test—System

1. **Query Image**
2. **Feature Extraction**
3. **Feature Database**
4. **Distance Calculations & Ranking**
5. **Retrieved Images**

- The process starts with a query image, which is extracted and compared against a feature database.
- Distance calculations determine the ranking of retrieved images.
Retrieval Result

![Graph showing retrieval result]

- **curvelet at 4 scale decomposition**
- **curvelet at 5 scale decomposition**
- **Gabor filter**
Retrieval Result

D002-002 as the query (top left image)
Retrieval Result

D018-002 as the query (top left image)
Retrieval Result

D091-003 as the query (top left image)
Conclusions

• Systematic description, implementation, analysis and evaluation of the curvelet transform.

• Application of curvelet transform on content based image retrieval and has produced a new texture feature.

• It is found that curvelet texture feature significantly outperforms the best texture features in literature such as the wavelet feature and the Gabor filter feature.

• In future, rotation and scale invariance will be investigated to further improve curvelet retrieval performance.

• Application of curvelet feature in color image retrieval and semantic learning will also be investigated.