DEEP DECOMPOSITION OF CIRCULARLY SYMMETRIC GABOR WAVELET FOR
ROTATION-INVARIANT TEXTURE IMAGE CLASSIFICATION
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Introduction

In recent years, deep learning technique has been studied extensively and got success in computer vision [8, 9] which shows that the good internal image representation is hierarchical. Motivated by deep learning, we propose Deep Decomposition of Circularly Symmetric Gabor Wavelet (DD-CSGW) based on CSGW which are rotation-invariant filters designed by Porter and Canagarajah [11] according to Gabor filters. Furthermore, we capture the dependence structure at each layer of DD-CSGW by using copula model to improve the classification performance.

For classification, the energies and standard deviations of DD-CSGW subbands as well as the parameters of copula models based on DD-CSGW are used as the features of texture image. SVM is utilized as the classifier for texture recognition. Experiments on texture databases show our method is effective compared with the state-of-the-art rotation-invariant methods.

CSGW

$$\text{CSGF}$$

$$g_c(x, y) = \frac{1}{2\pi\sigma} e^{-\frac{1}{2} \left(\frac{x^2 + y^2}{\sigma^2}\right)} e^{-2\pi ijWxy}$$

$$\text{CSGW}$$

$$g_n(x, y) = \lambda^{-n} h_c(x', y')$$

![Fig.1 CSGW with four different scales](image)

Properties

(1) CSGW can represent images on different scales
(2) CSGW is rotational invariant

Copula

Copulas have been employed in wavelet domain and achieved success for image analysis[12]. Copula theorem states that if \( H(x) \) is a multivariate cumulative distribution function of a random vector \( x = (x_1, ..., x_d) \), then it can be expressed by the margins \( F_1(x_1), ..., F_d(x_d) \) and a d-dimensional copula.

\[
H(x \mid \Theta) = C(F_1(x_1 \mid \delta_1), ..., F_d(x_d \mid \delta_d))
\]

Model CSGW subbands

(1) There exist strong dependencies between the subbands of CSGW
(2) Each subband can be model by a univariate distribution
(3) Copula is used to join these univariate distributions into a multivariate distribution

![Diagram of Copula](image)

Classification

\[
X = \begin{bmatrix} X_{CP}, & X_{cm} \end{bmatrix}
\]

\[
X_{CP} = \begin{bmatrix} \alpha_1^k, & \beta_1^k, & \cdots, & \alpha_k^i, & \beta_k^i, & \cdots, & \alpha_l^i, & \beta_l^i \end{bmatrix}_{l=1}^{K}
\]

\[
X_{cm} = \begin{bmatrix} \mu_1^k, & \epsilon_1^k, & \cdots, & \mu_l^i, & \epsilon_l^i \end{bmatrix}_{l=1}^{K}
\]

\(X_{CP}\): parameter feature set of copula model
\(X_{cm}\): feature set (energy and standard deviation features)
\(\mu\): norm-1 energy features
\(\epsilon\): norm-2 energy features
\(s\): standard deviation features

Classifier

We use Support Vector Machine (SVM) [14] as the classifier in our method.

Conclusion

DD-CSGW shows good performance for image representation compared to the state-of-the-art local descriptors. Deep decomposition is the highlight in this work, which remarkably improved the representation performance of CSGW and it can be applied into other undecimated wavelets such as Gabor wavelet.

Table 1. Classification rate on Outex database (%)

<table>
<thead>
<tr>
<th>Method</th>
<th>LTP</th>
<th>CTU10</th>
<th>CTU0010</th>
</tr>
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<tbody>
<tr>
<td>LBP</td>
<td>97.84</td>
<td>93.76</td>
<td>84.54</td>
</tr>
<tr>
<td>LTP</td>
<td>98.2</td>
<td>93.59</td>
<td>89.42</td>
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<tr>
<td>CLBP</td>
<td>99.38</td>
<td>94.98</td>
<td>95.51</td>
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<tr>
<td>DD-CSGW (Layer-1)</td>
<td>96.31</td>
<td>93.24</td>
<td>94.52</td>
</tr>
<tr>
<td>DD-CSGW (Layer-2)</td>
<td>97.86</td>
<td>97.04</td>
<td>98.38</td>
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<tr>
<td>DD-CSGW (Layer-3)</td>
<td>99.64</td>
<td>98.02</td>
<td>98.91</td>
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Table 2. Classification rate on UIUC database (%)

<table>
<thead>
<tr>
<th>Method</th>
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<th>CLBP</th>
<th>DD-CSGW (Layer-3)</th>
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<td>73.6</td>
<td>90.60</td>
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<td>DD-CSGW (Layer-3)</td>
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