Rotation, Scale and Translation Resilient Public Watermarking for Images

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Motivation: Print-and-Scan Process

- Pixel Value Distortion
- Geometric Distortion:
  -- Rotation, Scale,
  -- Translation, Crop
  Change of Boundary, Padding
Public Watermarking surviving Geometric Distortion

Identification
10101011100

Information
NECI

Characteristics: *Invisible, Robust and Blind*

- Previous Work:
Outline

- **Proposal:**
  - Embedding watermarks by shaping an invariant one-dimensional feature vector derived from the log-polar map of DFT of image.

- **Implementation Difficulties and Solutions:**

- **Experiments:**
  - False positive tests for 10,000 images;
  - Robustness tests for 2,000 images.

- **Conclusion and Future Work**
Discrete Fourier coefficients of discrete images after RST

• **Rotation** in spatial domain $\Rightarrow$ **Rotation** in frequency domain

\[
x_R(t_1, t_2) = x(t_1 \cos \theta - t_2 \sin \theta, t_1 \sin \theta + t_2 \cos \theta) \xrightarrow{F} X(f_1 \cos \theta - f_2 \sin \theta, f_1 \sin \theta + f_2 \cos \theta) = X_R(f_1, f_2)
\]

• **Scaling without change of boundary** in spatial domain $\Rightarrow$

**Scaling** in frequency domain

\[
x_S(t_1, t_2) = x\left(\frac{t_1}{\lambda_1}, \frac{t_2}{\lambda_2}\right) \xrightarrow{F} X(\lambda_1 f_1, \lambda_2 f_2) = X_S(f_1, f_2)
\]

• **Translation** in spatial domain $\Rightarrow$ **Phase shift** in frequency domain

• **Scaling with boundary change, Cropping** in spatial domain $\Rightarrow$ **Noise** in frequency domain
The Log-Polar Map of Fourier Coefficients

- Log-Polar Map
  - Rotation: shift in the $\theta$ axis
  - Scale: shift in the log $r$ axis.
  - Translation: no effect on the magnitudes.

Projection along the log $r$ axis:
- Cyclic shift for rotation,
- Invariant to scaling.

For RST (uniform scaling)
Watermark Embedding: Feature Vector Shaping

- Extract a Noise-Like Feature Vector and change it to a watermark pattern

Spread Spectrum:
\[ f( F_w ) = f( F ) + W \]

Feature Vector Shaping
\[ f( F_w ) \approx W \]

- Extract a Noise-Like Feature Vector and change it to a watermark pattern
Difficulties and Solutions

• Log-Polar Map of Fourier Coefficients:
  \textit{Solutions} $\Rightarrow$ Zero-Padding, bilinear interpolation from the magnitudes of DFT coefficients.

• Inverse Log-Polar Map (1-to-many, many-to-1 mapping):
  \textit{Solutions} $\Rightarrow$ Estimate changes from the log-polar map, and iterative embedding on the DFT coefficients.

• Noise-Like Feature Vector:
  \textit{Solutions} $\Rightarrow$ Local Variance, Whitening filter, Summing logs, Summing $g(\theta) + g(\theta + 90)$

• Visual Quality:
  \textit{Solutions} $\Rightarrow$ Constraint on the DFT Coefficient Variations.
DFT coefficients after rotation

- Characteristics: “cross” effect, Cartesian sampling points
  
  => **Solutions**: Estimate the cross positions from boundary/larger values
Algorithm for generating feature vector

1. Zero-padded to double image size
2. Calculate the magnitudes of log-polar coefficients, $|Fm|$, from DFT magnitudes
3. Summation of the log of the Fourier-Mellin magnitudes along log r axis
4. Combine values in orthogonal directions
   \[ g_1(\theta) = g_0(\theta) + g_0(\theta+90^\circ) \]
5. Subtract $g(\theta)$ by its global mean, (whitening filter)
6. The Feature Vector
   \[ fv = g(\theta_1, ..., \theta_n) \]
Experiments: Print-and-Scan

Original Image [384x256]  Watermarked Image, PSNR 43.8dB, $\rho=0.84$, $Z=7.02$

After Print & Scan, Crop to 402x266 => $\rho=0.80$, $Z=6.46$

After PS, Crop to 360x240 & JPEG CR: 95:1 => $\rho=0.64$, $Z=4.30$
Experiments: False Positive
(10,000 images from Corel Image Library, 10 different watermarks)
Experiments: Robustness
(ROC curves of 2,000 images)

Rotation
(4°, 8°, 30°, 45°)

Scale down
(5%, 10%, 15%, 20%)

Translation
(5%, 10%, 15%, 20%)

Scale Up
(5%, 10%, 15%, 30%)
Experiments: Robustness (ROC using 2,000 images)

JPEG Compression (100, 90, 80, 70)
Conclusion and Future Work

Conclusion:

• The watermarking method:
  – Utilize a signal that changes in a trivial manner as a result of RST.
  – Feature Vector Shaping: Embedding One-dimensional Watermark.

Related Work:


Future Work:

• Extensive test on the print-and-scan images.
• Enhance the robustness of the system in embedding multiple-bits watermark, and cropping.