Physics-Motivated Features for Distinguishing Photographic Images and Computer Graphics

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Background
Passive-blind Image Forensics

- Finding out the condition of an image without any prior information.
- Two main functions:
  - Image Forgery Detection
    - [Ng et al. 04] Photomontage Detection.
  - Image Source Identification
    - Photo vs. CG

Image Forgery Hall of Fame

LA Times '03  Internet '04  Nat. Geo. '92  Times '96
Prior Work

Photo vs. CG

- [Ianeva et al. 03] Classifying photo and general CG (including drawing and cartoon).
  - For the purpose of improving video key-frame retrieval.
- [Lyu & Farid 05] Classifying photo and photorealistic CG.
  - Using wavelet statistics.
  - 67% detection rate (1% false alarm).
  - Provides little insight into the physical differences between photo and CG.
Our Contributions

- A geometry-based image description framework
  - Motivated by the physical differences between Photo and CG.
- A two-level definition of image authenticity
  - Provides a systematic formulation and evaluation of an image forensics method.
- An effective classification model
  - Outperforms the methods in prior work.
- An open dataset
  - Avoids repeated data collection effort.
  - As a benchmark dataset.
- An online evaluation system.
  - Allows users to test the system.
Main Idea I

Definition of Image Authenticity

- **Camera authenticity**
  - Based on the characteristics of the camera.
  - **Local effect**: optical low-pass, color filter array interpolation, CCD sensor noise, white-balancing and non-linear gamma correction.
  - **Global effect**: lens distortion

- **Scene authenticity**
  - Based on the physics of light transport in the natural scenes.
  - **Global effect**: the orientation of a shadow is related to the lighting direction.
  - **Local effect**: real-world objects have complex reflectance model.

**Computer Graphics**

May be scene-authentic but not camera-authentic

**Photomontage**

May be camera-authentic but not scene-authentic
Main Idea I

Image Authenticity Life Cycle

Photo

Photomontage

Image Authenticity

Normal Post-processing

Transmission

Reconstruction

Excessive Post-processing

Recapturing

Post-processing

Camera Authenticity

Transmission

Reconstruction

Image-based Rendering

Combination

KEY

CG

Scene Authenticity
Main Idea II
Image Generative Process

Photographic Images

(1) Complex surface model
- Subsurface scattering of human skin.
- Color dependency.

(2) Complex object geometry
- Human skin texture follows biological system.
- Building surface formed by air erosion.

(3) Non-linear camera Transfer function
- Not an arbitrary transform.
Main Idea II

Image Generative Process

- Computer Graphics

3 Differences for Photo and CG
(1) Surface Model Difference.
(2) Object Model Difference.
(3) Acquisition Difference.

(1) Simplified surface model
- Assume color independence.

(2) Polygonal object geometry
- Reduced mesh resolution for computational efficiency.
- Without care, it introduces sharp structures in rendered images.

(3) Non-standard Post-processing
- Subject to the artist’s taste.
- May different from camera transform.

Post-processing

Light source
Main Idea III
Feature Correspondences

- Acquisition Difference
- Object Model Difference
- Surface Model Difference

Differential Geometry
- Image Gradient
- Quadratic Form
- Surface Laplacian

Fractal Geometry
- Distribution of the Local Fractal Dimension

Local Patch Statistics
- Distribution of the 3x3-pixels Local patches
Local Patch Statistics

- [Lee et al. 2003] 3x3 local patch forms a 2D sub-manifold in the normalized 8D Euclidean space.
- [Rosales et al. 2003] Use local patches to characterize image styles (e.g., Van Gogh Style).

Photo and CG are just images of different styles!
Local Patch Statistics

- We sample 4 types of patches.

Extract 4 types of patches

- High Contrast
- Low Contrast
- Grayscale
- Color

Patches projected to a 7-sphere in $\mathbb{R}^8$

Extract the rotational moment features from the distribution, as if the data points are the point masses of a rigid body.
Differential Geometry I

Image Gradient

- Non-linear camera transform has effects on image Gradient!

**Camera Model**

\[ r = \text{image irradiance} \]

\[ R = f(r) \]

**Camera Transfer Function**

**Chain Rule**

\[ \frac{dr}{dx} \]

\[ \frac{df}{dr} \]

Slope of the curve

\[ \frac{dR}{dx} = \frac{df}{dr} \cdot \frac{dr}{dx} \]

**Low Irradiance**

**High Irradiance**

**Expand**

**Compress**
Differential Geometry II

Quadratic Form

- Polygonal Model leads to sharp structures
  - At the junctures, the polygon is always sharper than the smooth curve.

A smooth is approximated by a polygon

Unusually sharp transition
A graph submanifold can be locally approximated by a quadratic form.

Quadratic form can be characterized by 2 eigenvalues.

The large eigenvalue implies sharp structures.

3D plot of elliptic Quadratic form.

Cross-section of the quadratic form at $z=1$.

Eigenvalues: $(1,1)$, $(2,1)$, $(3,1)$
Differential Geometry III

Surface Laplacian

Rendering of CG often assumes color independence in the object surface model (generally, not true for real-world object):

- We capture the difference in the RGB correlation for Photo and CG using the surface Laplacian.

- Laplacian operator ($\Delta_g$) on a graph surface
  - A vector pointing to the decreasing surface area direction.
  - For a submanifold in the 5D space, it measures the correlation between R, G and B.

\[ (\mathbf{R}, \mathbf{G}, \mathbf{B}) \quad (\Delta g I) = (\Delta g I_R, \Delta g I_G, \Delta g I_B) \]
Differential Geometry III

Surface Laplacian

Misalignment with 45 deg line

20% of CG has this misalignment, compared to only 5% of Photo.
Dataset
Columbia Open Dataset
- First publicly available Photo/CG dataset.
- Consists of 4 subsets, 800 images for each subset.

Available at http://www.ee.columbia.edu/trustfoto
Experimental Results I

SVM Classification

- SVM classification with radial basis function (RBF) kernel.
- Cartoon feature is the conventional feature for modeling the general computer graphics (includes cartoon or drawing)

<table>
<thead>
<tr>
<th>Features</th>
<th>Geometry</th>
<th>Wavelets</th>
<th>Cartoon</th>
</tr>
</thead>
<tbody>
<tr>
<td>Accuracy</td>
<td>83.5%</td>
<td>80.3%</td>
<td>71.0%</td>
</tr>
</tbody>
</table>

Receiver operating characteristic (ROC) curve

Photo Vs Internet CG
Experimental Results II

Recapturing Attack

- Testing with the recaptured CG (recapturing of a real scene)

<table>
<thead>
<tr>
<th>Features</th>
<th>Geometry</th>
<th>Wavelets</th>
</tr>
</thead>
<tbody>
<tr>
<td>Classified as Photo</td>
<td>97.2%</td>
<td>96.6%</td>
</tr>
</tbody>
</table>

- Counter-attack measure: Let the classifier learns the characteristics of the recaptured CG.

Receiver operating characteristic (ROC) curve

Good classification accuracy, counter-attack is successful!
The First Online CG-Photo Classification System

Photographic Image vs. Computer Graphics Detector (Version 4)

- Step 1. To submit a test image, please either enter its URL or select an image locally (not both):
  - URL
  - OR
  - Image File

- Step 2. There are 5 types of detectors based on different types of features, please select at least one that you are interested in:
  - A: Geometry feature
  - B: Wavelets Higher Order Statistics feature
  - C: Cartoon feature

- Step 3. Please indicate what type of image you are submitting and how confident you are about the type (Note that this information is not used in automatic classification. It is used for studying the difference between automatic detection and human judgment):

  - Image Type:
    - Photographic
    - Photorealistic CG
    - Non-photorealistic CG
    - Painting/Drawing
    - Hybrid
    - Others

  - Confidence Level:
    - Absolutely High
    - Quite High
    - Uncertain

- Fun: Browse recently submitted images and see if you can tell the image type...


URL: http://www.ee.columbia.edu/trustfoto/demo-photovscg.htm
### Photographic Image vs. Computer Graphics Detection Results

<table>
<thead>
<tr>
<th>Feature Type</th>
<th>Computation time</th>
<th>Detection Results</th>
<th>Chance to be a photograph</th>
</tr>
</thead>
<tbody>
<tr>
<td>Geometry Feature</td>
<td>4.88 seconds</td>
<td>Computer Graphics</td>
<td>0.01</td>
</tr>
<tr>
<td>Wavelet Feature</td>
<td>1.71 seconds</td>
<td>Computer Graphics</td>
<td>0.17</td>
</tr>
<tr>
<td>Cartoon Feature</td>
<td>0.62 seconds</td>
<td>Computer Graphics</td>
<td>0.01</td>
</tr>
<tr>
<td>Wavelet + Geometry + Cartoon Fusion</td>
<td>0.14 seconds</td>
<td>Computer Graphics</td>
<td>0.08</td>
</tr>
</tbody>
</table>

Format = JPEG  
Geometry = 586 x 419  
Colorspace = RGB  
Type = TrueColor  
Depth = 8

Image Information  
Detection Results  
Combined Classifier  

Return to the test page

This page is based on a perl-script from PerlScriptsJavaScipts.com
As one of the application scenarios, the cases with disagreement may be handed to experts for further analysis.
Conclusions and Future Work

Conclusions
- We propose a novel physics-based features.
- We provide the first publicly available Photo/CG dataset.
- We deploy the first online Photo Vs. CG classifier.

Future and Ongoing Work
- Camera transfer function estimation from a single image.
- Detecting Photo Vs. CG at the local regions.
- Designing counter-measure for the Oracle attack.
- Capturing global scene authenticity (e.g., consistency between lightings and shadows).
Thank you!

Dataset and Project Website: http://www.ee.columbia.edu/trustfoto
Online Demo: http://www.ee.columbia.edu/trustfoto/demo-photovscg.htm