A New Perspective on Material Classification and Ink Identification

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Presented by Joe Bartels, Zhe Cao
Ink classification based on bi-directional reflectance distribution function (BRDF)

<table>
<thead>
<tr>
<th>Image of the ink strokes</th>
<th>Ink classification result</th>
</tr>
</thead>
<tbody>
<tr>
<td>PILOT  EnerGel  Sharpie  Ball JS  Ball Om  Gel Jimnie  Perm Zig  Stabilo  Zebra  Perm PTL  Pencil</td>
<td>PILOT  EnerGel  Sharpie  Ball JS  Ball Om  Gel Jimnie  Perm Zig  Stabilo  Zebra  Perm PTL  Pencil</td>
</tr>
</tbody>
</table>
Related work on ink classification

- Disari [1] showed that statistical properties such as saturation histograms in HSV color space can differentiate ink.

Related work on material classification

Camera faces the surface head-on

Jinwei and Chao [4], CVPR ’12

Wang et. al [5], CVPR’09
Rusinkiewicz’s BRDF Parameterization

I – lighting direction
v – viewing direction
n – surface normal
h – bisector of I, v

Most of the BRDFs are 2D functions of $\theta_d$ and $\theta_h$
Limitation of Conventional Setup
Our New Perspective

I – lighting direction
v – viewing direction
n – surface normal
h – bisector of I, v
Experiments on ink classification

Reflectance info is recorded by

\[ f(\theta_d, \theta_h) = \frac{I(x)}{(n \cdot l)} \]
Conventional Setup vs. Our New Perspective

78% vs. 85%
Handheld Capture Method

- BRDF slices over

\[ \theta_h = \left[ 0, \frac{\pi}{2} \right] \]

\[ \theta_d = 0 \]
Reflectance Properties

Captures retro-reflectance:
\[ \theta_d = 0 \]
\[ \theta_h > \frac{\pi}{3} \]

However does not capture Fresnel effects:
\[ \theta_d > \frac{\pi}{3} \]
Handheld Capture Method Accuracy

• Classification accuracy of 71%
• Conventional 1D method had 78% accuracy
• True 2D BRDF 85%
• Error comes partly from imprecision in registration of handheld camera positions
BRDF Slice Intervals

• Some slice intervals may be more informative than others
• Train new SVM classifier on overlapping regions of BRDF slice
• Accuracy is highest in the specular reflection and retro-reflection intervals
• Accuracy of using full slice is better than any single interval
Number of Images

Convention 1D Data Capture

Handheld Capture Method
## Ink Classification Results

<table>
<thead>
<tr>
<th>Training Data</th>
<th>Test Data</th>
<th>Training Results</th>
<th>Test Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>_______</td>
<td>PILOT</td>
<td>_______</td>
<td>PILOT</td>
</tr>
<tr>
<td>_______</td>
<td>ENERGL</td>
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<td>ENERGL</td>
</tr>
<tr>
<td>_______</td>
<td>SHARPIE</td>
<td>_______</td>
<td>SHARPIE</td>
</tr>
<tr>
<td>_______</td>
<td>BALL JS</td>
<td>_______</td>
<td>BALL JS</td>
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<tr>
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<td>PERM PTL</td>
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<td>PERM PTL</td>
</tr>
<tr>
<td>_______</td>
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<td>_______</td>
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</tr>
<tr>
<td>_______</td>
<td>PENCIL</td>
<td>_______</td>
<td>PENCIL</td>
</tr>
</tbody>
</table>

The table above shows the ink classification results for both training and test data. The training data includes several pen brands, and the test data consists of the same pens with different colors. The results show how well the classification model performs on both datasets.
Ink Classification Results

<table>
<thead>
<tr>
<th>Actual Label</th>
<th>Pilot</th>
<th>Stabilo</th>
<th>EnerGel</th>
<th>Jimmie</th>
<th>Ball JS</th>
<th>Ball OM</th>
<th>Zebra</th>
<th>Sharpie</th>
<th>PermPtl</th>
<th>PermZig</th>
<th>Pencil 1</th>
<th>Pencil 2</th>
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</thead>
<tbody>
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<td>0.3</td>
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<td>4.1</td>
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<td>0</td>
<td>0</td>
<td>0</td>
<td>1.3</td>
<td>0.8</td>
</tr>
</tbody>
</table>

Accuracies:
- OM: 55.9
- NCI: 98.3
Line Results

Input

Results

Ground Truth

Legend

Fountain
Ball OM
Zebra
Stabilo
Check Forgery Detection

Input

Results

Ground Truth
Positive Contributions

• First work that applies material classification to document analysis
• First use of reflectance properties to identify ink
• Developed method to capture a larger portion of 2D BRDF domain than the conventional near 1D BRDF slices.
• Method increased ink classification accuracy from 78% to 85%.
• Handheld flashlight camera for ink identification
  – Captures specular reflection and retro-reflectance
  – Requires fewer input images than previous methods and allows for more flexible data capturing
Paper Shortcomings

- Assumes prior knowledge of BRDF slices, maybe that is okay. A short description or image of how the prior work did it would have been nice.
- A more detailed description of training the SVM classifier (e.g., whether to sample the lighting direction, how to adjust pixel difference) will be helpful for readers to replicate the results.
- Several typos.
Technical Correctness

- **Method shortcomings:**
  - Authors said that some error in handheld camera system was caused by registration error
  - Handheld system registration error could be caused from multiple sources including estimating normals from the interpolated surface shape
    - Maybe improve by directly finding normals and depth with handheld photometric stereo methods by Higo, Matsushita, Joshi and Ikeuchi, ICCV 2009
  - Handheld flashlight camera doesn’t capture Fresnel effects for increased performance
Summary

• Improvement in classification performance can be achieved by simply setting the camera at a slanted view to capture a larger portion of the 2D BRDF domain.

• Handheld flashlight camera can capture important reflectance properties such as specular reflection and retro-reflectance for material classification.

• Rating: 2- Accept