SkyFinder: Attribute-based Sky Image Search

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Abstract

- Interactive search system of over a half million sky images
- Automatically extracted semantic sky attributes
  - Category, layout, richness, horizon, sun position
Abstract

- Applications
  - Sky graph
  - Sky replacement
Introduction

- Commercial search engines are based only on text
  - Noisy, low quality, and disorganized
  - Page-by-page browsing

- CBIR systems can find similar images to a query image
  - Need to provide a good query image

*CBIR : content based image retrieval
Introduction

• Offline indexing process
  ▪ Semantic sky attributes are automatically extracted
    • Category, layout, richness, horizon, sun position

• Online search
  ▪ Interactively search sky images based on sky attributes

• Applications
  ▪ Sky graph
  ▪ Sky replacement
Contribution

• Simple attribute based “text” search
  ▪ Not content based image search, but similar semantic results

• Three novel building blocks:
  ▪ Sky attributes design and automatic extraction techniques
  ▪ User interface for search
  ▪ Path finding algorithm in the sky space
Related works

- Leveraging a large image collection
  - Scene Completion [Hays and Efros 2007]
  - Face Swapping [Bitouk et al. 2008]
  - Photo Tourism [Snavely et al. 2006]

- Two works most related to ours
  - Semantic photo Synthesis [Johnson et al. 2006]
  - Photo Clip Art [Lalonde et al. 2008a]
Sky Attributes

Data collection

- Download 1.3 million images from flickr

- Training data
  - Randomly pick a number of images
  - Manually label it
    - Blue-sky (500N)
    - Cloudy-sky (700N)
    - Sunset (800N)
    - Uncertain images are disregarded
  - Separate sky and non-sky regions
    - Interactive image cutout tool [Li et al. 2004]
    - Sky region map used to train automatic sky region segmentation
Sky Attributes

Extraction of sky Attributes - Category

- Represent image as a “bag-of-words”
  - A collection of evenly sampled 16X16 patches
    - Patch is represented by SIFT descriptor and mean HSV color
    - Each assigned to the nearest code word

- A code book with 2,500 code words is learned
  - Performing Randomized Forests Algorithm [Moosmann et al. 2006]
Sky Attributes

Extraction of sky Attributes - Category

• **SVM classifiers** are trained for three categories
  ▪ Blue-sky classifier is trained
    • Blue-sky training images are positive examples
    • Other training images are negative examples

• For each image, apply the three classifiers
  and use the three SVM scores as its category attribute
Sky Attributes

Extraction of sky Attributes - Layout

- Individually train a sky/non-sky pixel classifier for three categories
  - Uses the same visual descriptor (SIFT, mean HSV color)
  - Uses patch from the sky/non-sky region within the category as the positive/negative examples

- Choose Randomized Forests as our classifier

![SVM Score](image1)

GraphCut

![Binary sky region map](image2)
Sky Attributes

Extraction of sky Attributes - Layout

• Estimate the line of horizon
  ▪ Moving a horizontal line upwards from the bottom of the image
• Categorize a sky into one of five types

: Bounding Box – cover 95% sky pixels

A : \( \frac{\# \text{ sky pixels}}{\# \text{ pixels}} \) in the bounding box

: Horizon height
Sky Attributes

Extraction of sky Attributes - Horizon

• Discretize the height of the horizon into eight levels
  ▪ Enhance the user control over the layout
  ▪ Useful for automatic sky replacement
Sky Attributes

Extraction of sky Attributes - Sun

• Detect the existence and position of the sun
  ▪ For sunset and cloudy-sky category
  ▪ Not for blue-sky (containing ratio is small)

• In the Sunset category
  ▪ Brightness is greater than a threshold in the magenta channel

• the Cloudy-sky category
  ▪ Brightness is greater than a threshold in the black channel

*Using CMYK color space
Sky Attributes

Extraction of sky Attributes - Sun

• A Sun is detected
  ▪ Aspect ratio of the detection region is within the range [0.4, 2.5]
  ▪ Ratio of region’s area to the area of region’s bounding box is greater than 0.5
Sky Attributes

Extraction of sky Attributes - Richness

- The richness of the clouds can be roughly characterized by the amount of image edges
  - Linear combination of edge numbers detected by filters
    - Canny detector for small scale edges
    - Sobel detector for middle and large scale edges

- The edge number \( n \) of the image is:

\[
    n = k \cdot n_s \cdot s \left( -\frac{n_s - 1000}{100} \right) + n_c \cdot s \left( \frac{n_s - 1000}{100} \right)
\]

- Quantize the edge number into five intervals

\[ns\text{ : edge numbers by Sobel detector}\]
\[nc\text{ : edge numbers by Canny detector}\]
\[k\text{ : constant parameter}\]
\[s\text{ : sigmoid function}\]
Sky Attributes

Quantitative evaluations

- Performed a study on nearly 6,000 test sky images
  - Manually label it as one of three category
  - Separate sky and non-sky regions
  - Identify the sun existence/position

- Overall performance is high:
  - The precision/recall are over 85% in most cases

<table>
<thead>
<tr>
<th></th>
<th>blue-sky (P/R)</th>
<th>cloudy-sky (P/R)</th>
<th>sunset (P/R)</th>
</tr>
</thead>
<tbody>
<tr>
<td>category classification</td>
<td>99.2% / 96.7%</td>
<td>88.8% / 94.7%</td>
<td>97.3% / 98.2%</td>
</tr>
<tr>
<td>sky segmentation</td>
<td>95.2% / 93.6%</td>
<td><strong>88.9% / 96.6%</strong></td>
<td>92.2% / 95.4%</td>
</tr>
<tr>
<td>sun detection</td>
<td>- / -</td>
<td>80.8% / 82.5%</td>
<td><strong>91.3% / 72.6%</strong></td>
</tr>
</tbody>
</table>
Attribute-Based Search

User Interface

• Category
  ▪ Sky images lie approximately on a flat “triangle” in 3D
    • Each image has three SVM scores
  ▪ Project these points into 2D using PCA
  ▪ Find a minimal-area 2D triangle

• Horizon and sun canvas
  ▪ Draw the positions of horizon and the sun

• Layout and richness
  ▪ Select layout and richness attributes through two drop-down lists
Attribute-Based Search

User Interface

- Left: (2D)category triangle
- Right: horizon and sun canvas, and layout and richness controls
### Attribute-Based Search

#### An example

<table>
<thead>
<tr>
<th>(a)</th>
<th>Random</th>
</tr>
</thead>
<tbody>
<tr>
<td>(b)</td>
<td>+ Blue-sky</td>
</tr>
<tr>
<td>(c)</td>
<td>+ Richness</td>
</tr>
<tr>
<td>(d)</td>
<td>+ Landscape</td>
</tr>
<tr>
<td>(e)</td>
<td>+ Horizon</td>
</tr>
<tr>
<td>(f)</td>
<td>+ Color-based re-ranking res</td>
</tr>
</tbody>
</table>
Attribute-Based Search

Color based re-ranking

- Sky color representation
  - Color signature: \( s = \{w_k, c_k\}_{k=1}^3 \)
    - \( w_k \) is a weight, \( c_k \) is a color in LAB space
    - Obtained using k-means clustering

- Similarity
  - Earth Mover’s Distance (EMD)

Figure 6: Another search example. (a) sunset + landscape + horizon + sun position. (b) color based re-ranking results.
Path search

**Sky graph**

- Build a sky image graph and find a smooth path
  - Attribute based search to obtain a sparse graph

- Sparse graph using attributes
  - 1. use category and richness attributes -> 2000 candidates
  - 2. re-rank candidates by color -> Top 200 neighbors
  - 3. use color similarity (EMD) as edge weight
Path search

Finding a path

• Compute min-max shortest cost path
  ▪ Not standard shortest path algorithm
  ▪ Limiting the max-transition-cost

Figure 7: Path search. (a) results by the shortest path. (b) results by the min-max cost shortest path.
Sky replacement

- Blue-sky or cloudy-sky category
  - Compute the color transfer variables between two sky regions
  - Apply the variables to the non-sky region
Sky replacement

- Sunset category
  - Directly transfer the color of the source non-sky region to the target non-sky region
Sky replacement
Sky replacement

**Figure 9:** Replacement results using a searched path.
Conclusion

• The several issues:
  ▪ Improve the sky/non-sky segmentation
  ▪ Reduce the errors in horizon estimation
  ▪ Add cloud attributes such as cirrus, altocumulus, and cumulus

Figure 10: Inaccurate sky segmentation. Dark-red is the segmentation mask and light-red is the ground-truth.