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Sky Color Enhancement of Photographic Images

Huanzhao Zeng, Google Inc.

Abstract

Blue sky color is an important memory color for outdoor photography. Reproducing it pleasingly is essential for preferred color reproduction of photographic images. A simple approach for enhancing blue sky color is to detect blue sky colors and then enhance all sky blue pixels regardless of their object types. However, this method has a negative effect for modifying blue colors of non-sky objects. In this paper, we present an improved method for detecting the sky region of images captured with digital cameras, followed with a method to enhance blue sky colors for visually pleasing results. Treatment of white sky colors (overexposed sky colors and white clouds) and sunset and sunrise warm sky colors are presented as well.

1. Introduction

Reproducing memory colors pleasing is essential for preferred color reproduction of photographic images. Skin tone, green foliage, and blue sky are the main categories of memory colors. Preferred reproduction of these three prototypical colors is essential for improving perceptual image quality.

In this paper, we focus on the color enhancement of sky colors, which includes two parts, sky detection and sky color enhancement. Color classification is a simple approach to detect blue sky colors. Saber et al. [1] assumed sky pixels to follow a 2-D Gaussian probability function, and therefore Mahalonobis distance, along with an adaptive determined threshold, was applied to determine sky pixels. Quan and Jin [2] utilized hue angles to determine blue sky colors. You and Chien [3] segmented the sky area and then enhanced the saturation of the region with a factor determined by an average saturation of the whole sky region and a weight computed from the relative pixel position and the original saturation. Luo and Etz [4] developed a model-based sky segmentation method consisting of color classification, region extraction, and physical-motivated sky signature validation. Gallagher et al. [5] improved this detection algorithm based on a 2-D polynomial model of the blue sky. Takahashi and Hirata [6] proposed a sky detection method enabling robust region detection for cloudy sky by evaluating similarity of visual features between combined regions of segmented regions from an input image and the sky region stored in a database. Quach et al. [7] implemented a blue-sky detection method for real-time blue sky detection and used it for the noise reduction and color enhancement of blue sky for HDTV. Fredemback et al. [8] utilized PCA-based feature detection to segment blue sky. Zafarifar and With [9] applied a probability based method for sky detection, in which probabilities of blue sky color, sky texture and noise, and location are joined considered for sky detection.

Bartleson and Bray [10] found that the preferred reproduction of blue sky in color prints corresponded to a more “purple-blue” color than the memory color. Hunt et al. [11] found that preferred blue sky color had an appreciably higher purity than the original sky color. Studying the color preference and perceived color naturalness of digital video, Koh et al. [12] found that blue sky looked more pleasing when its color was purer and deeper. The author’s study confirms that people prefer deeper blue sky color of images in print and of photos and videos on display, however, the preferred blue sky hue is less consistent.

Based on Zafarifar and With approach, the author developed a sky detection method to determine a blue sky region of an upright image, divided the image into a sky region on the top and a non-sky region on the bottom, and applied polynomial regression to produce a smooth boundary that separates two objects. A color enhancement method was developed to enhance sky colors. Blue sky, white sky, white cloud, sunset and sunrise, etc., were considered together for visually pleasing results. The methods of blue sky detection and color enhancement, and results are presented in following sections.

2. Sky Detection

Sky, in general, has no hard edges and is relatively smooth. We assume images are upright oriented, which can be detected by the camera gyro. Sky and non-sky boundary is initially searched from top to bottom by finding hard edges. A thick edges map is generated from a thumbnail image. First, gradient is calculated by following equations

$$grad_{hor}(r,c) = \frac{1}{N_{grad}}\left(\sum_{i=-w}^{w}\sum_{j=-w}^{-1} Y(r+i,c+j) - \sum_{i=-w}^{w}\sum_{j=1}^{w} Y(r+i,c+j)\right)$$

$$grad_{ver}(r,c) = \frac{1}{N_{grad}}\left(\sum_{i=-w}^{-1}\sum_{j=-w}^{w} Y(r+i,c+j) - \sum_{i=1}^{w}\sum_{j=-w}^{w} Y(r+i,c+j)\right)$$

where w is a half-window size.

Next, gradient probability is computed by

$$P_{grad} = e^{-\left([T_{vl} - grad_{ver}]_0^{\infty} + [grad_{ver} - T_{vu}]_0^{\infty} + [|grad_{hor}| - T_h]_0^{\infty}\right)^2}$$

where T_{vl} and T_{vu} are thresholds for the lower and the upper bounds of the vertical gradient respectively, and T_h is the threshold for the horizontal gradient. X_0^{∞} = X if X > 0, or 0 if X <= 0. Fig. 1-(a) shows a few test images, and Fig. 1-(b) is the result of gradient probability map.

In order to use P_{grad} to generate a boundary curve that separate sky and non-sky, high P_{grad} points in the sky region need to be remove and broken lines on sky to non-sky boundary need to be connected. For this purpose, local activity information is added to compute the probability. Sum of absolute differences (SAD) of horizontal adjacent lines in an analysis window are computed by:

$$SAD_{hor}(r,c) = \frac{1}{N_{SAD}}\sum_{i=-w}^{w}\sum_{j=-w}^{w-1} |Y(r+i,c+j) - Y(r+i,c+j+1)|$$

$$SAD_{ver}(r,c) = \frac{1}{N_{SAD}}\sum_{i=-w}^{w-1}\sum_{j=-w}^{w} |Y(r+i,c+j) - Y(r+i+1,c+j)|$$

Activity is computed by equation

$$P_{activity} = e^{-\left([SAD_{hor} + SAD_{ver} - T_{SAD}]_0^{\infty}\right)^2}$$

where T_{SAD} is a noise threshold.

The texture probability is updated as the product of the activity probability and the gradient probability:

$$P_{texture} = P_{activity} \cdot P_{grad}$$

Fig. 1-(c) show the result of the texture probability maps of the test images. Now sky is cleaner and the boundary line between sky and non-sky is better connected.

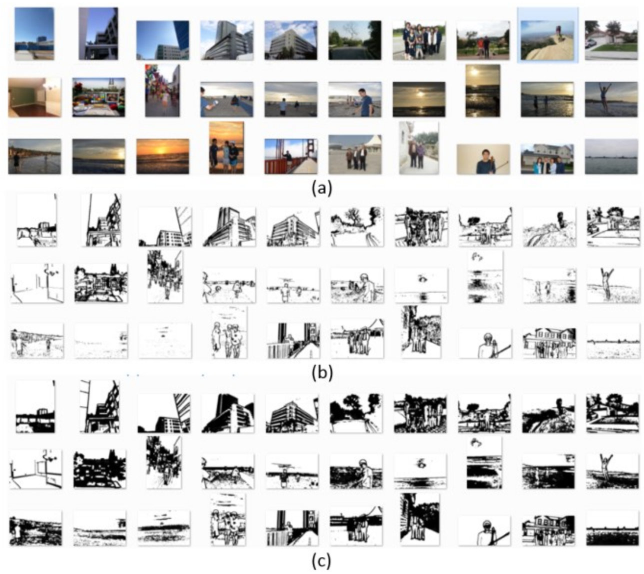

Figure 1. (a) Original images, (b) Gradient map, (c) Texture map

So far, color information has not been applied. Sky colors include blue, white (cloud and overexposed sky), and red and orange (sunset and sunrise). Since our sky color enhancement is to modify blue and white colors only and not to touch sun, sunrise and sunset sky colors, the sky color modelling is only to detect blue and white colors only. After testing different blue sky color models, an elliptical model is adapted for sky color detection [13]. The model is trained in YCbCr color space to improve the computation efficiency. A normalized Mahalanobis distance, r, of a color to the blue sky center is computed. Sky color likelihood is computed by equation

$$P_{color} = e^{(-r^2)}$$

Sky probability model becomes

$$P = P_{texture} \cdot P_{color}$$

Since images are assumed upright oriented, sky likelihood gradually reduces from top to bottom. An exponential function, P_{color}, to reduce the probability gradually from top to bottom is added to the sky probability model. Sky probability map is computed as the product of texture probability, position probability, and color probability:

$$P = P_{texture} \cdot P_{position} \cdot P_{color}$$

In general, blue sky is bright. As a color gets too dark, its probability to be a sky color diminishes. Although this is not always true, it is a good choice for color enhancement because we do not want to adjust very dark blue sky colors. A probability term based on brightness is added to compute the sky probability:

$$P = P_{texture} \cdot P_{color} \cdot P_{location} \cdot P_{brightness}$$

Texture probability is computed in a single channel. If the texture probability map is computed in the luma channel, strong edges are often found around clouds and over-exposed white regions, which leads to trouble in sky to non-sky separation. The issue is fixed by calculating texture in the blue channel instead (see Fig. 2).

Since small isolated edges (noise, small objects such as birds and airplanes) can cause problem for searching sky/non-sky boundary from top-down direction, a post processing step is applied to remove small isolated dots and edges.

Figure 2. Converting color images to a single channel image for computing texture map

Finally, a curve fitting algorithm is applied to produce a boundary line that divides an image into a sky region and a non-sky region. Fig. 3 shows an example. The black curve is the detection boundary, and the red line is a fitting straight line for the boundary. Because color adjustment gradually diminishes as a pixel location approaches the boundary, an accurate separation boundary is not required. Hence, a smooth fitting curve generated with polynomial regression can be used instead.

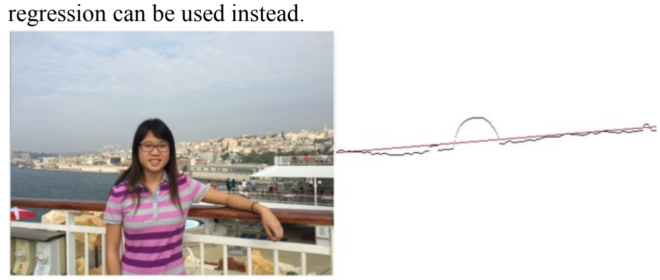

Figure 3. Sky boundary of a test image

3. Sky Color Enhancement

To produce deeper blue sky colors, we increase saturation or add blue (or reduce green and red) to the sky region. Gain adjustment factors, r_gain, g_gain, and b_gain, for R, G, and B channels are applied to modulate R, G, and B pixel values. Full adjustments are applied to sky pixels located far away from the boundary, and the adjustment strengths are gradually reduce and eventually diminish on or close to the boundary. Instead of increasing B value, R and G values may be reduced to increase the blue saturation. By adjusting R, G, and B gains, blue sky hue can be moved to a more preferred direction as well.

If a simple curve fitting is applied (e.g. a straight line is fitted) to produce a boundary line, some non-sky objects will be included in the sky region. This is mostly fine for trees because green trees appear more greenish. It is generally fine for buildings, for human eyes tend to feel the blue tint comes from blue sky reflections. But, if human faces are included in the sky region, adding blue to faces damages face tones. Also, blue should not be added to yellowish or reddish sun, sunrise skies, and sunset skies. To save-guard colors of objects, such as sun and faces, hue angle on each pixel within the sky region on a thumbnail image is verified. If it is not within the hue range from green to blue and saturation is above a threshold, it is not processed.

In Fig. 4, the sky boundary is fitted with a straight line (red line in the figure) for color enhancement. Due to the hue verification, colors on the red flag and the face are not affected.

In order to preserve yellowish and reddish sunrise and sunset sky colors, and to save guard skin tones, colors of each column from top to the boundary are averaged. If the mean color is not blue or white, the boundary point of the column is moved up. With this process, sunrise and sunset skies are prevented from processing (see Fig 5).

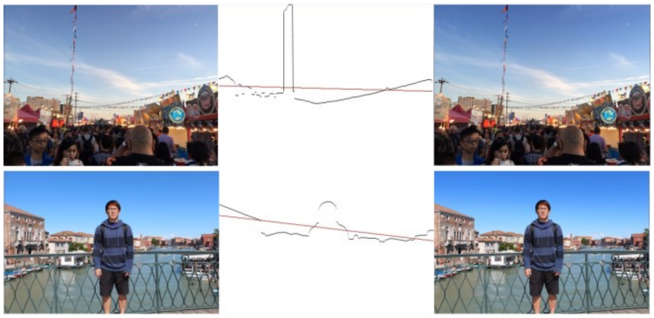

Figure 4. Blue sky enhancement result: original (left), sky boundary (center), enhanced (right)

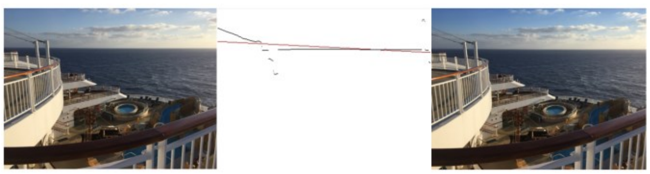

Figure 5. Blue sky enhancement result: original (left), sky boundary (center), enhanced (right)

When a scene is captured with a camera, the blue sky is sometimes overexposed and becomes white. During the sky color enhancement, we check white and near white colors. Based on preference in tuning camera color, we may add blue tint to these colors. Fig. 6 shows an example of preserving white sky (on left) and processing white sky (on right).

Figure 6. Sky color enhancement: preserve white sky (left), process white sky (right)

All of the sky detection and sky color enhancement are processed on a thumbnail image. The final result is an RGB mask, which represents RGB gains (adjustment factors) of each thumbnail pixel. The mask is then applied to process the original image for fast sky color processing.

4. Conclusions

A sky color enhancement method was developed to produce more pleasing sky colors. Sky detection is applied to detect a sky boundary. The boundary line is modified if the sky is detected yellowish or reddish (sunset or sunrise scenes). We find that an exact sky boundary is not required for sky color enhancement, and apply a curve fitting method to produce a smooth boundary curve for smooth color adjustment. In the sky region, colors are analyzed to avoid processing colors of important objects (e.g. sun and human faces). White cloud and white sky colors may be enhanced or preserved to meet personal color preference requirements. The sky detection and color enhancements are processed on a down-scaled thumbnail image for fast processing. The processed thumbnail mask is then applied to process the full-resolution image for sky color enhancement.

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Author Biography

Huanzhao Zeng recently joined Android Team at Google as a senior color imaging scientist. He was a senior color imaging scientist at Qualcomm from 2012 to 2015, developing color imaging technologies for e-reader displays and mobile phone cameras. Before that, he was a principal color imaging engineer at Hewlett-Packard Company for 12 years, working on color architect, color image processing, gamut mapping, ICC color management system for high-speed inkjet printing systems, multi-function and commercial printers, and photo-mini-labs. He received his Ph.D. degree in Colour Science from University of Leeds, and M.S. degree in Imaging Science from Rochester Institute of Technology.