Comparison of Color Spaces for Histogram-Based Image Retrieval

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Abstract

In this paper, we investigate the appropriateness of the three well-known color spaces, i.e., RGB, YUV, and HSV, for histogram-based color image retrieval. An image retrieval demo system is built to make it easy to test the retrieval performance. In our demo system, each image is first transformed into the investigated color space. Then, the histogram for each color channel of the image is obtained, which is served as the color feature of the image. We have performed experiments on a database with 1000 images, using the Euclidean distance metric. The results show that the HSV color space outperforms the other two color spaces from the aspect of the histogram-based color image retrieval.

Key Words : Color space, content-based image retrieval, query-by-example, color histogram.

1. Introduction

Digital contents are becoming an important medium for information collection and exchange. Given the exploding market on digital photo and video camera's, the fast growing amount of image content further increases the need for image retrieval systems. Generally, image retrieval procedures can be roughly divided into two approaches: query-by-text (QbT) and query-by-example (QbE). In QbT, queries are texts and targets are images; in QbE, queries are images and targets are images. For practicality, images in QbT retrieval are often annotated by words, such as time, place, or photographer. To access the desired image data, the seeker can construct queries using homogeneous descriptions, such as keywords, to match these annotations. Such retrieval is known as annotation-based image retrieval (ABIR). ABIR has the following drawbacks. First, manual image annotation is time-consuming and therefore costly. Second, human annotation is subjective. Furthermore, some images could not be annotated because it is difficult to describe their content with words. On the other hand, annotations are not necessary in a QbE setting, although they can be used. The retrieval is carried out according to the image contents. Such retrieval is known as content-based image retrieval (CBIR) [5]. CBIR has received a large amount of attention over the last 10 years. Smeulder et al. [10] reviewed
CBIR is a technology to search for similar images to a query based only on the image pixel representation. However, the query based on pixel information is quite time-consuming because it is necessary to devise a means of describing the location of each pixel and its intensity. Therefore, how to choose a suitable color space and reduce the data to be computed is a critical problem in image retrieval. In this paper, we investigate the appropriateness of the three well-known color spaces, i.e., RGB, YUV, and HSV, for CBIR.

In our demo system, each image is first transformed from the standard RGB color space into the YUV (or HSV) space. Then, the histogram for each component (e.g., luminance Y, blue chrominance U, and red chrominance V) of the image is obtained, which can be served as the color feature of the image. In the image database establishing phase, the features of each image are stored; in the image retrieving phase, the system compares the features of the query image with those of the images in the database, using the Euclidean distance Metric and find out good matches.

The rest of this paper is organized as follows. Section 2 and 3 introduce the color space and color histogram. Section 4 presents the distance measure. Section 5 shows the experimental results. Finally, conclusions are drawn in Section 6.

2. Color Space

A color space is a model for representing color in terms of intensity values. It specifies how color information is represented. There exist many models [4] through which to define the valid colors in image data, e.g. RGB (Red, Green, and Blue), CMYK (Cyan, Magenta, Yellow, and Black Key), CIE (Centre International d’Eclairage), YUV (Luminance and Chroma channels), and HSV (Hue, Saturation, and Value), etc. Each of the models is specified by a vector of values; each component of that vector being valid on a specified range. The details of RGB, YUV, and HSV color spaces are introduced as follows.

2.1 RGB Color Space

A gray-level digital image can be defined to be a function of two variables, f(x, y), where x and y are spatial coordinates, and the amplitude f at a given pair of coordinates is called the intensity of the image at that point. Every digital image is composed of a finite number of elements, called pixels, each with a particular location and a finite value. Similarly, for a color image, each pixel (x, y) consists of three components: R(x, y), G(x, y), and B(x, y), each of which corresponds to the intensity of the red, green, and blue color in the pixel, respectively.

2.2 YUV Color Space

Originally used for PAL (European "standard") analog video, YUV is based on the CIE Y primary, and also chrominance. The Y primary was specifically designed to follow the luminous efficiency function of human eyes. Chrominance is the difference between a color and a reference white at the same luminance. The following equations are used to convert from RGB to YUV color space:

\[ Y = 0.299R + 0.587G + 0.114B, \]  
\[ U = 0.492(B - Y), \text{and} \]  
\[ V = 0.877(R - Y). \]

Basically, the Y, U, and V components of an image can be regarded as the luminance, the
blue chrominance, and the red chrominance, respectively. From Eq. (2), it can be found that the blue chrominance $U$ is obtained from removing the luminance component $Y$ from the blue component $B$; the red chrominance $V$ is obtained similarly. After converting from RGB to YUV, the color features can be extracted more easily. For example, if we need to verify whether an image’s color tone is red or not, it makes vain attempt to analyze the $R$ component of the RGB image because most of the energy of the $R$ component contributes to the luminance of the image; on the other hand, just like the philosophy lies in the orthogonal theorem, it is more effective to analyze the $V$ component of the image, which eliminates the component that constitutes the luminance of the image.

2.3 HSV Color Space

The HSV stands for the Hue, Saturation, and Value based on the artists (Tint, Shade, and Tone). The Value represents intensity of a color, which is decoupled from the color information in the represented image. The hue and saturation components are intimately related to the way human eye perceives color resulting in image processing algorithms with physiological basis.

As hue varies from 0 to 1.0, the corresponding colors vary from red, through yellow, green, cyan, blue, and magenta, back to red, so that there are actually red values both at 0 and 1.0. As saturation varies from 0 to 1.0, the corresponding colors (hues) vary from unsaturated (shades of gray) to fully saturated (no white component). As value, or brightness, varies from 0 to 1.0, the corresponding colors become increasingly brighter. The conversion formula from RGB to HSV color space is as follows:
Figure 2. The color histograms for each component of the image shown in Figure 1(a); the (a)R, (b)G, (c)B components in the RGB color space, and the (d)Y, (e)U, (f)V components in the YUV color space, and the (g)H, (h)S, (i)V components in the HSV color space.

\[
H = \cos^{-1}\left(\frac{[(R - G) + (R - B)]/2}{\sqrt{(R - G)^2 + (R - B)(G - B)}}\right) \quad (4)
\]

\[
S = 1 - 3 \times \left[\min(R, G, B) / (R + G + B)\right], \quad (5)
\]

\[
V = (R + G + B) / 3. \quad (6)
\]

A sample image, which contains red flowers, green grasses, and blue skies, is purposely selected to illustrate the RGB, YUV and HSV color spaces (see Figure 1).

**3. Color Histogram**

The color histogram for an image is constructed by discretizing (or quantizing) the colors within the image and counting the number of pixels of each color. More formally, it is defined as

\[
h_{x,y,z}(x, y, z) = N \cdot \text{Prob}(X = x, Y = y, Z = z), \quad (7)
\]

where \(X\), \(Y\) and \(Z\) represent the three color channels (\(R, G, B\), or \(Y, U, V\), or \(H, S, V\)) and \(N\) is the number of pixels in the image.

The color histogram can be regarded as a set of vectors. For gray-scale images these are 2-D vectors. One dimension gives the value of the gray-level and the other the count of pixels at the gray-level. As for color images each color channel can be regarded as gray-scale images.

Figure 2 gives the color histograms for each component of the image shown in Figure 1(a); the number of bins in these histograms is set to 10. It can be found that the shape of the histogram derived from the \(Y\) component (see Figure 2(d)) is similar to that derived from the \(G\) component (see Figure 2(b)); it is because \(G\) is the dominant component that constitutes the \(Y\) component (see Eq. (1)).

More generally, we can set the number of bins in the color histograms to obtain the feature vector of desired size.

**4. Distance Measurement**

To decide which image in the image database is the most similar one with the query image, we have to define a measure to indicate the degree of similarity. Therefore, the distance (or dissimilarity) between a feature vector \(F_m\) of the query image and that of an image in the database is based on the distance function.

**4.1 Distance Function**

In our approach, the distance between two vectors is calculated on the basis of the sum of squared differences (SSD). Assume that \(F_{qm}\) and \(F_{xm}\) represent the \(m\)th feature of the query image \(Q\) and an image \(X\) in the database, respectively; each feature may come from the color histograms. Then, the distance between \(F_{qm}\) and \(F_{xm}\) can be defined as
\[ d_m(F_{qm}, F_{xm}) = \sum_{i=1}^{K-1} (F_{qm}[i] - F_{xm}[i])^2, \quad (8) \]

where \( i \) is the \( i \)th coefficient of the \( m \)th feature and \( ||F_{qm}|| = ||F_{xm}|| = K \).

4.2 Weighting Vector

Since several features are used simultaneously, it is necessary to integrate similarity scores resulting from each individual feature. In our case, the total distance can be derived from the following equation:

\[ D(Q, X) = \sum_{m=1}^{M} w_m d_m(F_{qm}, F_{xm}). \quad (9) \]

Here, \( Q \) and \( X \) are the query image and one of the images in the image database, respectively. \( d_m \) is the distance function defined as Eq. (8); \( w_m \in R \) is the weight of the \( m \)th feature; \( M \) is the number of feature being considered. In the demo system, all weights are set to 1.

5. Experimental Results

We evaluated performance on a test image database, which was downloaded from the WBIIS database [11]. It is a general-purpose database including 1,000 color images. The images are mostly photographic and have various contents, such as natural scenes, animals, insects, building, people, and so on. In the experiment, an image retrieval demo system is built to test the retrieval performance. We have performed experiments on a database with 1000 images, using the Euclidean distance metric. The results show that the HSV color space outperforms the other two color spaces from the aspect of the histogram-based color image retrieval.

To assess the ground-truth relevance score to each image for each benchmark query, each target image in the collection is assigned a relevance score as follows: 1 if it belonged to the same class as the query image, 0.5 if partially relevant to the query image, and 0 otherwise. Then, a quantitative retrieval effectiveness measure, called precision, can be computed. The precision rate measures the efficiency with which the relevant items are returned among the best \( k \) matches. On the basis of precision, the retrieval effectiveness for each color space can be evaluated. A more effective one shows a higher precision rate.

The retrieved images using the three benchmark query images are shown in Figures 4, 5, and 6, respectively. The bin number for each component image is set to 5. Tables 1 to 3 show the retrieval effectiveness for each color space using different query image. The average top 10 precision rates of the three benchmark queries for each color space are shown in Figure 7. It can be found that the HSV is the best and the YUV is the second, in terms of the precision rates.

6. Conclusions

In this paper, we investigate the appropriateness of the three well-known color spaces, i.e., RGB, YUV, and HSV, for histogram-based color image retrieval. An image retrieval demo system is built to make it easy to test the retrieval performance. We have performed experiments on a database with 1000 images, using the Euclidean distance metric. The results show that the HSV color space outperforms the other two color spaces from the aspect of the histogram-based color image retrieval.
References


Figure 3. The GUI of our demo system.
Figure 4. Query 1. (a) The query image, and the retrieved results based on three color spaces: (b) RGB, (c) YUV, and (d) HSV.

Figure 5. Query 2. (a) The query image, and the retrieved results based on three color spaces: (b) RGB, (c) YUV, and (d) HSV.
Figure 6. Query 3. (a) The query image, and the retrieved results based on three color spaces: (b) RGB, (c) YUV, and (d) HSV.

### Table 1 Query 1: Eagle – Comparison of Three Color Spaces

<table>
<thead>
<tr>
<th>Color Space</th>
<th>RGB</th>
<th>YUV</th>
<th>HSV</th>
</tr>
</thead>
<tbody>
<tr>
<td># Relevant in Top 10</td>
<td>5</td>
<td>6</td>
<td>10</td>
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### Table 2 Query 2: Owl – Comparison of Three Color Spaces

<table>
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<th>HSV</th>
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</thead>
<tbody>
<tr>
<td># Relevant in Top 10</td>
<td>3.5</td>
<td>5</td>
<td>4</td>
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</table>

### Table 3 Query 3: Pink Flower – Comparison of Three Color Spaces

<table>
<thead>
<tr>
<th>Color Space</th>
<th>RGB</th>
<th>YUV</th>
<th>HSV</th>
</tr>
</thead>
<tbody>
<tr>
<td># Relevant in Top 10</td>
<td>3</td>
<td>6</td>
<td>7</td>
</tr>
</tbody>
</table>
Figure 7. Average precision rate of the three color spaces for the three benchmark queries.