PROPERTIES OF DOMINANT COLOR TEMPERATURE DESCRIPTOR

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Abstract: The concept of color temperature is derived from an innate characteristics of the human visual system. It is formulated as a visual feature referring to a kind of perceptual feeling about perceived light. Color temperature has also a physical-based definition, and hence, color temperature of observed scenes and visual objects can be modelled in a mathematical way as a one-parameter characteristics of perceived light. In the Amendment to the Visual Part of the MPEG-7 Standard the Color Temperature descriptor for image browsing has been proposed. To extend the functionality of content-based image search by color temperature we proposed the Dominant Color Temperatures descriptor, which allows a user to perform query by example and query by value searches. The extraction algorithm was originally adopted from dominant color's one, which utilizes vector quantization in 3D color space. We also proposed a second, much faster algorithm based on scalar quantization in one-dimensional color temperature space. In this paper we present a comparison of the two extraction algorithms. We also compare the querying results of the Dominant Color Temperature descriptor and two conceptually related descriptors: Dominant Color and Color Temperature.

1 INTRODUCTION

Color temperature is a feature of light, associated with color (Wyszecki, Stils, 1982), and is derived from light perception of the human visual system. Color temperature is a promising feature in content-based image indexing, because viewers can easily judge perceptual image similarity using color temperature. The Amendment to the Visual Part of the MPEG-7 Standard (ISO/IEC, 2004) specifies the Color Temperature descriptor, which refers to the color temperature of image scene illumination (Kim, Park, 2001a). It is extracted by an iterative procedure, in which the average color of pixels having significant influence on color temperature perception is estimated. This descriptor is mainly intended for image browsing by classification of images into one of the four given subjective color temperature categories: hot, warm, moderate, cool. Its usefulness in search tasks of other kinds, such as query by example or query by color temperature value is rather poor. Another limitation of this descriptor is that images may contain a few regions of different color temperatures, in such a case the average color only roughly estimates the perceived color temperature of images, and a significant piece of information about color temperature content might be lost.

In some applications the user may want to have the possibility for a more powerful searching, and for a more precise ranking of query results than it is possible using the simple Color Temperature descriptor. Moreover, two other kinds of queries for color temperature-based search, in addition to the subjective categorization, may be of the user interest. The first is a query by value, in which the user simply inputs the required color temperature in Kelvin degrees, and the system retrieves images having the perceived color temperature closest to the user input. The second type of query is a query by example, in which the user chooses an example image, and the system retrieves the most similar ones. The example image may be a real image or an image drawn by the user as a colored sketch. This type of query is possible for other color descriptors contained in the MPEG-7 Standard (ISO/IEC, 2002b): Color Histogram (Scalable Color), Dominant Color, Color Structure, Color Layout, but is not available for the Color Temperature descriptor. These two search functionalities can be

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achieved using Dominant Color Temperatures descriptor, which describes a few representative color temperatures in an image. We proposed two algorithms for extraction of the descriptor. One of them is similar to the extraction method of the MPEG-7 Dominant Color descriptor (Wnukowicz, 2004). But that method is not optimally suited for dominant color temperatures extraction, and is also computationally costly (vector quantization of pixel values in 3D color space). To avoid these drawbacks, we proposed a new extraction algorithm (Wnukowicz, 2005) based on scalar quantization in one-dimensional color temperature domain. The syntax of the Dominant Color Temperatures descriptor remains the same as the originally proposed one. Section 2 outlines the extraction methods, and section 3 presents experiments for comparison of the methods.

Although Dominant Color Temperature descriptor relates conceptually to two other descriptors: Dominant Color and Color Temperature, there are significant differences between them. We carried out some experiments for comparing the results obtained by those descriptors and Dominant Color Temperatures descriptor for a test dataset of images. They are presented in sections 4 and 5.

2 EXTRACTING DOMINANT COLOR TEMPERATURES

The general idea of the Dominant Color Temperatures descriptor is to describe images by color temperatures of their representative colors. This will result in more precise description of images regarding color temperature feature in comparison with the one-parameter Color Temperature descriptor. The Dominant Color Temperature descriptor extends the functionality of image searching using color temperature by enabling two additional types of queries: query by color temperature value and query by example. Other types of queries are also possible, of which examples are the following:

– find images that contain at least 80% of dominant colors with warm color temperature category;
– find images that contain regions of different color temperature categories (for example warm>20% and moderate>40%);
– rank query result according to the relevance to the user query.

The originally proposed method for dominant color temperatures extraction is based on the extraction algorithm for dominant colors (ISO/IEC, 2002a). This solution is justified by the fact that perceptually distinct dominant colors are obtained by averaging color values of similar group of pixels in an image. The averaging of color values for pixels which influence color temperature perception is also used in extraction of the Color Temperature descriptor (Kim, Park, 2001b).

The overall scheme of the dominant-color-based extraction method can be outlined in the following steps:

1. Extract the dominant colors of an image using the GLA color quantization algorithm;
2. Compute the chromaticity coordinates on *uv* plane for each dominant color;
3. Compute the color temperatures from the chromaticity coordinates for each dominant color;
4. Construct the descriptor as an array of elements that hold values and percentages of the color temperatures in the image. The “black” colors are not included into the descriptor.

To extract the descriptor, first, up to eight dominant colors of the image are obtained, and next, color temperatures for the dominant colors are estimated. As a result K pairs of values $[t_i, p_i]$ are obtained, where t_i denotes color temperature value, p_i denotes percentage of pixels with color temperature t_i, $0 \le i \le K\text{-}1$, and $K \le 8$.

The dominant color based approach for dominant color temperatures extraction has two significant drawbacks. The first is a high computational cost caused by the vector quantization of pixel values in 3D color space. The second drawback is that dominant colors do not always correspond to distinct color temperature values. For example, two distinct dominant colors, light-red and dark-red, may have undistinguishable color temperatures. The better solution would be if the dominant color temperatures were well distinguishable. Such solution is the extraction method proposed in the second algorithm (Wnukowicz, 2005).

The new extraction algorithm is based on scalar quantization in one-dimensional color temperature domain. The algorithm can be outlined in the following steps:

1. Compute color temperature values, in reciprocal megakelvin scale, for all pixels in the image;
2. Mark pixels without significant color temperature values, that should be omitted (e.g. black colors);
3. Compute a histogram of color temperature for the remaining pixels;
4. Perform scalar quantization of the histogram bins to obtain dominant color temperatures;
5. Merge similar dominant color temperature bins (by using a merging threshold).

The histogram is computed from pixel samples represented by color temperature values. The values of color temperature are converted to reciprocal megakelvin scale (mired, $1MK^{-1}$=1000000/K), which is usually used in color temperature calculations instead of Kelvin scale. Values of the samples are clipped to the range from 40 MK^{-1} (25000K) to 600 MK^{-1} (1667K), and quantized with step q. The resulting histogram has (600-40)/q bins. We used q=1, what gives 560 bins in the histogram. Scalar quantization is performed by modified Lloyd algorithm (Lloyd, 1982) in color temperature histogram domain. The range of color temperature values is being split into K subranges, the mass centers of the histogram subranges are considered to be the representative points of the relevant subranges. The algorithm calculates (locally) optimal division of the color temperature range into K subranges having minimum distortion. The distortion is calculated as a sum of distances from the representative points of each subrange to the color temperature values represented by positions of histogram bins contained within this subrange, weighted by values of the relevant histogram bins. K obtained representative points are candidates for the dominant color temperatures. In the next step, the color temperature representative points which are closer to each other than a given merging threshold T_{merg} are merged to obtain perceptually distinct dominant color temperatures.

3 COMPARISON OF THE EXTRACTION METHODS

The experiments for comparison of the two extraction methods were performed using a test dataset from core experiments of the MPEG-7 Color Temperature descriptor (Kim et al., 2001c). In those experiments 3056 test images were classified into four color temperature categories according to subjective user's voting. The subjective categories were: hot (reddish colors dominate), warm (orange and yellowish colors), moderate (white, grey, green colors) and cool (bluish colors).

Figure 1 and 2 show graphs which depict ranking of query result of the test images for moderate color temperature category. The graphs depict relationships between the viewer's subjective assessment of images and the ranking of query results for the two extraction methods of Dominant Color Temperatures descriptor. The vertical axes in both graphs represent percentage of viewer's votes assigning images to moderate color temperature category. The horizontal axes represent image positions on the ranked result lists for moderate category. Figure 1 shows the result for the new extraction method (scalar quantization), and figure 2 shows the result for the original extraction method. The ranking of query result were done according to the distance to reference color temperature of a chosen subjective category as explained in (Wnukowicz, 2004), and the reference color temperature RT_{REF}=181,92 MK^{-1} was taken for the experiments (the middle of the moderate category subrange in reciprocal scale). The user votes (given in %) were smoothed in the graphs by averaging in a shifted window of 50 consecutive images. As it can be intuitively assumed, it is desirable that images positioned at the beginning of the result list had the percentages of viewer's votes close to 100%.

Figure 1: Ranking of query result for the scalar-quantization-based extraction algorithm

Figure 2: Ranking of query result for the dominant-color-based extraction algorithm

Additionally, the graphs contain lines which best fit the smoothed relationships for the two descriptions. The line parameters were obtained by linear regression of the data. The equation of the approximated line is $y=a*x+b$, where x is the image position (horizontal axis of the graph), y is the smoothed percentage of votes value, a is the slope of the line, and b is the intersection of the line with the vertical axis of the graph (intercept, percentage of votes for the first positioned image on the retrieved list). Table 1 shows start points (b parameter values) of the lines for all of the four subjective color temperature categories, table 2 shows average deviations of the data points from the approximated lines. In table 1 the bigger value is the better. In table 2 the smaller value is the better.

Table 1: The first point of the regression line (b parameter)

Color temperature category	Scalar quantization	Dominant color quantization
Hot	91.69	92.26
Warm	75.23	73.76
Moderate	87.12	86.5
Cool	87.91	87.46

Table 2: Average squared deviation of percentage of votes (regarding regression line)

Color temperature category	Scalar quantization	Dominant color quantization
Hot	5.36	5.47
Warm	13.03	15.7
Moderate	13.13	11.42
Cool	6.98	6.22

The main advantage of the new extraction method is a significant decrease of the computational complexity, as it utilizes scalar quantization of 1D color temperature histogram with fixed size instead of vector quantization in 3D color space with complexity depending on image size. In the case of vector quantization, the most time consuming task is an iterative process of clustering, which is performed by finding the nearest representative point for each pixel of the indexed image, until the change of quantization error in two consecutive iterations comes down below an established threshold. For example, if we have an image of the size MxN and K representative color points, the number of distance calculations needed is MxNxK, The distance between two colors $[l_1, u_1, v_1]$ and $[l_2, u_2, v_2]$ in 3D color space is given by: $(l_1 - l_2)^2 + (u_1 - u_2)^2 + (v_1 - v_2)^2$, where l, u, v are color components in LUV color space, which is used due to its perceptual homogeneity. It means that computation of a single distance requires 3 subtractions, 3 multiplications and 2 additions. For M=256, N=256, K=8, the number of distance calculations in a single clustering step is: 256 x 256 x 8 = 524288. Quantization may need a few dozen iterations of clustering.

In the case of color temperature histogram the quantization is performed in one dimensional space for data of fixed size. The clustering is done, by assigning subrange's cut points between neighboring representative color temperature values. The quantization error is computed by summing up the distances from the representative points to assigned to them color temperature values represented by histogram bins, weighted by histogram bin values. This task needs B distance calculations, involving two basic operations: subtraction and multiplication, where B is the number of histogram bins (e.g. B=560). Experiments showed that even for small images (384x256) the generation of indexes is more than two times faster when the new algorithm is used. For bigger images the difference in computation time could be even greater.

4 COMPARISON OF DOMINANT COLOR TEMPERATURES AND COLOR TEMPERATURES

To compare the Dominant Color Temperature descriptor and the Color Temperature descriptor, experiments of ranking the search results were carried out, where matching according to human perception was evaluated. It was assumed that the order of retrieved images should match the user perception. The measure of matching to subjective tests was performed by evaluation of smoothed vote percentage graphs in image rank domain, which was obtained as specified in the previous section.

Experiments were performed for all of the four color temperature categories, for the Dominant Color Temperature descriptor, and for the Color Temperature descriptor. In the case of Color Temperature descriptor the query results were ranked according to the distance from color temperature of image to the reference color temperature value of relevant subjective category. The graph of the query result ranking for the moderate color temperature category is depicted in figure 3. Tables 3 and 4 contain the parameters of estimated regression lines for all categories.

The results of the experiments show that searching by the Dominant Color Temperature descriptor matches the subjective assessment of color temperature. This matching is generally better than in the case of the Color Temperature descriptor, but the largest improvement is achieved for moderate category, as it can be easy seen when comparing the graph in figure 3 with the ranking of the Dominant Color Temperature descriptor depicted in figures 1 and 2. This is due to the fact that images which belong to the moderate category have the largest variation of dominant colors, and the varied dominant color temperatures could not be well discriminated by one-parameter descriptor.

Figure 3: Ranking of query result for Color Temperature descriptor (moderate category)

Table 3: The first point of the regression line (b parameter)

Color temperature category	Dominant color temperatures	Color temperature
Hot	91.69	90.83
Warm	75.23	74.12
Moderate	87.12	66.14
Cool	87.91	84.91

Table 4: Average squared deviation of percentage of votes (regarding regression line)

Color temperature category	Dominant color temperatures	Color temperature
Hot	24.96	5.47
Warm	7.039	15.7
Moderate	20.34	11.42
Cool	12.58	6.22

The experiments show that in the case of the Dominant Color Temperatures descriptor the user perception corresponds better to search results obtained for all of the four subjective color temperature categories with the following reference values: 1667K (hot), 2924K (warm), 5497K (moderate), 25000K (cool). However, this justifies the suitability of this descriptor to be used for any other color temperature value that a user may want to query for in a search application.

5 COMPARISON OF DOMINANT COLOR TEMPERATURES AND DOMINANT COLOR

Although the Dominant Color Temperature descriptor is based on the Dominant Color descriptor, there are significant differences between them. We carried out some tests comparing the query results obtained by the two descriptors for test images from the dataset.

There are at least three conceptual differences between the two descriptors:

– differences between concepts of color and color temperature. Dominant colors in an image of a dissimilar appearance may at the same time make an impression about the image to be similar regarding their dominant color temperatures, e.g. gray/green, orange/pink;
– different concepts of similarity measure for query by example. In the case of the Dominant Color descriptor, images are considered to be similar if they have regions with very close colors and similar percentages (ISO/IEC, 2002a). Images can have minor regions with highly dissimilar colors. In the case of Dominant Color Temperature the emphasis is on the overall similarity of dominant color temperatures and their percentages, so single regions which have dissimilar color temperatures make images be more dissimilar;
– the Dominant Color Temperature descriptor is intended to be an enhancement of the Color Temperature descriptor by functionalities such as query by example, query by value, image ranking, and searching for images with multiple color temperatures.

To compare the Dominant Color descriptor and the Dominant Color Temperature descriptor a set of queries has been performed for the test dataset (3056 images) and image positions on the retrieved lists were registered.

The result of experiments for comparing the ranking of query results for the two descriptors is presented in the graph in figure 4. The graph shows histogram of correlation of ranked query results for the two descriptors: Dominant Colors and Dominant Color Temperatures. The variables used for computing the correlations were image positions on two ranked result lists obtained for the two descriptors (image positions were in the range from 1 to 3056). For each image from the test dataset two queries using the two descriptors were performed, the results were ranked and the positions of retrieved images were registered, which were used as input variables to compute the correlation of image positions.

Correlations were computed for 3056 queries (each image in the dataset was a query), and the histogram presents the results (correlation values are smoothed with step 0.01). Pearson formula was used to compute the correlation, where 0 means no correlation between variables, 1 indicates maximum correlation (the datasets are the same), -1 means that variables are inversely correlated.

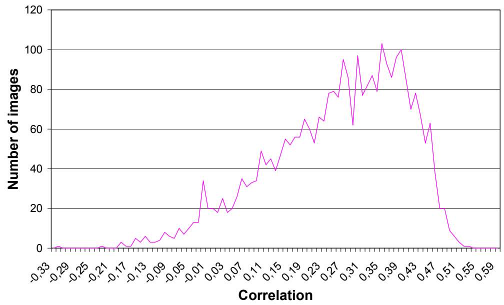

Figure 4: Correlation of query results for Dominant Color Temperatures and Dominant Color descriptors

As it can be seen in the diagram, the correlations span values from -0.32 to 0.53, but the average value is about 0.26, so the correlation between results obtained by dominant colors and dominant color temperatures is not very high. This confirms that the two descriptors give different search functionalities.

6 CONCLUSIONS

We have presented some experiments demonstrating the properties of the Dominant Color Temperatures descriptor, which was designed for content-based image searching. First, two available extraction algorithms have been compared. The originally proposed algorithm makes it possible to extract the Dominant Color Temperatures descriptor directly from the Dominant Color descriptor, what may be an advantage in same cases. But generally the new algorithm, which uses fast scalar quantization in color temperature domain, is a better solution for extraction of the Dominant Color Temperatures description.

We also compared this descriptor with two conceptually related visual descriptors: Color Temperature and Dominant Color. On the one hand the Dominant Color Temperatures descriptor can be regarded as an enhancement to the Color Temperature descriptor – it support new functionalities of searching by color temperature. On the other hand it have significantly different properties than the Dominant Color descriptor.

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