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Colour temperature estimation algorithm for digital images – properties and convergence

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The paper presents an algorithm for estimation of temperature of image. Colour temperature is important, perceptual feature describing colour and content of images. The main idea of the algorithm is to average pixel values of image, omitting the values which have meaningless influence on perception of colour temperature. It is done in an iterative procedure. The convergence of the procedure is discussed. The algorithm can be applied in image search/retrieval tasks and is proposed in the MPEG-7 colour temperature descriptor for estimation of colour temperature of images.

Keywords: colour temperature, colour perception, image retrieval.

1. Introduction

Colour temperature is one of the visual features essentially influencing perception of colour by the human visual system. Categories such as hot, warm, moderate, and cool are used for describing the felt temperature of the touched objects. The same categories can be considered in the case of colour temperature feeling by observer who is viewing colour scene or image. This feeling depends mostly on properties of illumination of the viewed scene. Different kinds of illumination of the same scene gives different colour temperature feelings, adequately to the illumination. For example, natural daylight can have light in broad range of colour temperature values depending on the time of the day as well as atmospheric and weather conditions which have an influence on colour temperature perception in outdoor images. The view of the same landscape in various viewing conditions such as a sunny day at noon, cloudy sky or at twilight gives varied feelings of colour temperature. In the same way works artificial light – different light sources can give different colour temperature feelings for the illuminated scene.

The concept of colour temperature is not explicitly related to thermal temperature of the viewed objects. It is derived from a relationship between the temperature of a hypothetical object called black body and its appeared colour. The colour chromaticity of black body just depends on temperature of this body. Being based on this assumption one can classify colours in the range from hot to cold according to its similarity to of colour black body in appropriate temperature.

This article presents a colour temperature estimation algorithm for image to represent general visual impression of colour temperature a viewer has of the image. The impression depends on elements like image colour content, illumination of the scene while it was photographed, and to some extent on observation conditions. The procedure consists of two main steps. In the first step, the image average colour value is computed by omitting pixels having poor influence on colour temperature impression. In the second step, the colour temperature value is estimated for previously computed colour, utilizing its chromaticity coordinate values. It is done by Robertson's algorithm [1] which approximates colour temperature by means of the fixed lines on *uv* chromaticity diagram called isotemperature lines.

The estimated colour temperature of image can be classified into one of subjective categories: hot, warm, moderate, and cold. The whole range of colour temperature values should be divided into 4 sub-ranges. This task was approached by conducting subjective experiments on a group of people who visually assessed test images with respect to colour temperature feeling. The result of the assessment was used for partition objectively computed colour temperature values into the subjective categories [2].

The estimated colour temperature could be applied for image indexing and searching engines and is proposed as a basis for a new visual descriptor in MPEG-7 standard [3,4].

2. Procedure for estimation of temperature of image

A basic definition of colour temperature can be stated as an absolute temperature of the black body whose spectral distribution of radiance power is proportional to the given stimulus. It means that the both radiations have the same

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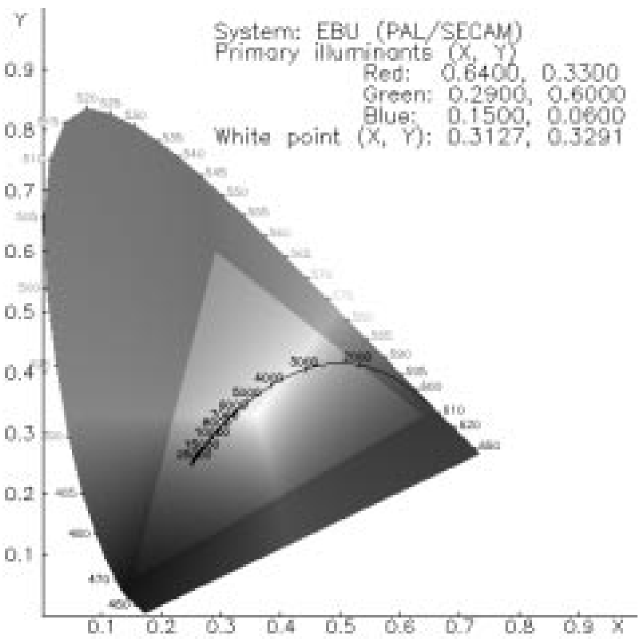

Fig. 1. Planck's locus of black body on *xy* chromaticity diagram.

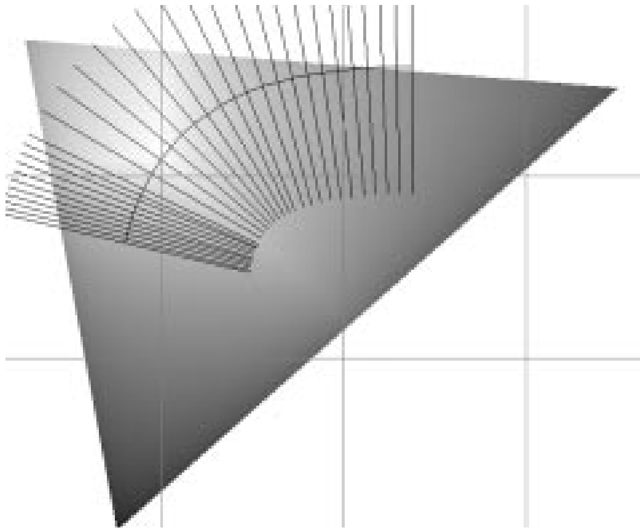

Fig. 2. Isotemperature lines on the uv chromaticity diagram.

chromaticity values. The chromaticity of black body radiation depends only on its temperature and is defined by Planck's formula [1]. It is convenient to depict this dependency on a chromaticity diagram. Figure 1 shows the curved line named Planck's locus, corresponding to the chromaticity of a black body at the temperature changing from 2000 K (red colour) to 25000 K (blue colour).

Because of the fact that having the basic definition of colour temperature it can be determined only for a small set of colours, a correlated colour temperature concept is introduced. A correlated colour temperature is the temperature of Planck's black body whose perceived colour most closely resembles that of the given stimulus. So, it is defined rather in perceptual aspect. In practice, the term of colour temperature is used also for correlated colour temperature for shortness. The calculation of colour temperature is performed by use of the perceptually homogeneous UV chromaticity diagram (CIE 1960). It is assumed that the colour temperature is constant along the lines which are perpendicular to the Planck's locus on this diagram (Fig. 2). These short straight lines are called isotemperature lines.

The algorithm for calculation of the chromaticity coordinates of image has its main steps as follows:

- linearize image pixels: *RGB –> sRGB*,
- convert colour space *sRGB –> XYZ*,
- discard pixels with Y luminance value below threshold T_l,
- iteratively average remaining pixels discarding the ones with values above a threshold adapted after each iteration,
- take chromaticity coordinates (x_s,y_s) of average colour given in *XYZ*.

The estimation of colour temperature for the given colour has the steps as follows:

- convert chromaticity coordinates from (x_s,y_s) to (u_s,v_s) (according to CIE 1960 UCS),
- find two adjecent isotemperature lines, from collection of 31 isotemperature lines, which are neighbours to the point (u_s,v_s) on the chromaticity diagram,
- compute value of colour temperature from the distance ratio between the point and both of the two adjacent isotemperature lines.

3. Calculation of the perceptional average chromaticity coordinates of image

In the first stage of colour temperature estimation there are computed the chromaticity coordinates of average colour of image pixels related to human perception of colour temperature. Pixels which have poor or meaningless influence on this perception are discarded during calculation. Firstly, image pixels are converted into standard linear colour space *sRGB* [5]. Equation

$$\text{if } R(i,j) \le 0.03928 \times 255.0$$

$$R_{sRGB}(i,j) = \left(\frac{R(i,j)}{255 \times 12.92}\right)$$

$$\text{else} \tag{1}$$

$$R_{sRGB}(i,j) = \left[\frac{\dfrac{R(i,j)}{255} + 0.055}{1.055}\right]^{2.4}$$

presents calculation of *R* colour component for most commonly available images represented in the form suited to PC computer monitors. The *G* and *B* components are converted in the same way. Parameters *i* and *j* indicate the pixel position in rows and columns respectively.

The obtained *sRGB* colour components are in the range [0,1], what simplifies further computation. Next, pixel values are converted into *XYZ* colour space by multiplying the conversion matrix *M* and the *sRGB* colour vectors

$$\begin{bmatrix} X(i,j) \\ Y(i,j) \\ Z(i,j) \end{bmatrix} = M \times \begin{bmatrix} R(i,j) \\ G(i,j) \\ B(i,j) \end{bmatrix}, \tag{2}$$

where

$$M = \begin{bmatrix} 0.4124 & 0.3576 & 0.1805 \\ 0.2126 & 0.7152 & 0.0722 \\ 0.0193 & 0.1192 & 0.9505 \end{bmatrix}$$

Black and near black colours do not impact significantly colour temperature perception, so the dark pixels are omitted from calculation. The auxiliary table p is a mask for marking discarded pixels. This is a matrix which has the same dimensions as the image. If the mask value at the specific position $p(i,j)$ is 0 then the corresponding pixel in the image is omitted from further calculations. T_{ll} is a threshold for pixel discarding having its typical value 5% of maximal component range. Only the luminance component Y is used for discarding dark pixels

$$\begin{cases} \text{if } Y(i,j) < T_{ll} & \text{then } \; p(i,j) = 0 \\ \text{else} & \qquad\;\; p(i,j) = 1 \end{cases}. \tag{3}$$

In the next step, the remaining pixels are iteratively averaged. In this process, a threshold for indicating colours standing out is assessed in each iteration and pixels exceeding the threshold are marked for omitting. The pixels discarded here are too much different from the averaged mean value and represent self-luminous regions or objects [6]

$$\begin{aligned} & X_{Ts}(0) = 0 \\ & \text{loop} \\ & X_a = \frac{1}{row \times col} \sum_{i=0}^{row-1} \sum_{j=0}^{col-1} X(i,j), \\ & X_{Ts} = f \times X_a \\ & \text{if } (X_{Ts}(t) = X_{Ts}(t-1)) \text{ return } X_a \\ & \begin{cases} \text{if } X(i,j) > X_{Ts} & \text{then } \; p(i,j) = 0 \\ \text{else} & \qquad\;\; p(i,j) = 1 \end{cases} \\ & \text{end loop} \end{aligned} \tag{4}$$

In averaging procedure, Eq. (4), $X_{Ts}(t)$ indicates the threshold in the current loop t above which the pixels are discarded. If the threshold value is the same as in the previous loop [$X_{Ts}(t-1)$], it means that no pixels were discarded in that loop and the mean value X_a is returned. The computation of mean value X_a is done only for pixels which have corresponding mask value $p(i, j)$ above 0. The same is for expression $row{\times}cols$. It intuitively means: “the number of pixels not indicated for discarding”. The averaging procedure is carried out for all of the three colour components X, Y and Z. The f coefficient is a multiplier for the colour component average value to obtain threshold above which pixels are discarded. Its typical value is 3, what was obtained in the subjective experiments [6].

The procedure for averaging image pixels was verified on a test set of images. Typical number of iterations for the test images was in the range from 4 to 8 depending on the pixel value distributions in images. Maximum number of iterations was above 20. The convergence of the averaging procedure can be described as in Eq. (5).

Let $A_n = \overline{X}_n$, $K_n = |X_n|$, and S_n is a sum of pixel values in the set X_n, and n is the loop number

$$S_n = K_n A_n \left(A_n = \frac{S_n}{K_n} \right)$$

and

$$S_n = S_{n+1} + \sum_{\substack{x \in X_n \\ x > fA_n}} x,$$

where

$$\begin{aligned} K_n A_n &= K_{n+1} A_{n+1} + \sum_{\substack{x \in X_n \\ x > fA_n}} x \geq \\ &\geq K_{n+1} A_{n+1} + f A_n (K_n - K_{n+1}), \\ A_n (K_n - fK_n + fK_{n+1}) &\geq K_{n+1} A_{n+1}, \\ A_{n+1} &\leq A_n \left[\frac{(1-f)K_n + fK_{n+1}}{K_{n+1}} \right] = \\ &= A_n \left[f - (f-1) \frac{K_n}{K_{n+1}} \right]. \end{aligned} \tag{5}$$

A_n is the decreasing sequence if

$$\left[f - (f-1) \frac{K_n}{K_{n+1}} \right] \leq 1,$$

thus

$$\left[(f-1) \left(1 - \frac{K_n}{K_{n+1}} \right) \right] \leq 0.$$

It is true because $f > 1$ and $K_n >= K_{n+1}$, therefore $0 \leq A_{n+1} \leq A_n$. The sequence is convergent because it is not increasing and is lower bounded.

The (x_s, y_s) chromaticity values are obtained from computed average colour as follows.

$$\begin{aligned} x_s &= \frac{X_a}{X_a + Y_a + Z_a}, \\ y_s &= \frac{Y_a}{X_a + Y_a + Z_a}. \end{aligned} \tag{6}$$

4. Estimation of colour temperature of given colour

After computing the chromaticity coordinates of the average colour of image, its colour temperature can be estimated. Firstly, the chromaticity coordinates need to be converted to (u_s,v_s) coordinates according to the CIE

$$u_s = \frac{4x_s}{-2x_s + 12y_s + 3} \qquad v_s = \frac{6y_s}{-2x_s + 12y_s + 3} \tag{7}$$

Secondly, the line perpendicular to the Planck's locus, the crossing point (u_s,v_s), must be determined on the diagram. The line in question is an isotemperature line for the obtained averaged image colour. For this purpose, Robertson's algorithm can be used [1], which utilizes 31 fixed isotemperature lines given in the form of parameters gathered in a table. The given isotemperature lines are within a range from 1667 K to 100000 K, and they are specified by 4 parameters: their colour temperatures T_i and geometrical locations on a diagram, which are tangents of an angle between the line and the horizontal direction t_i and the point of crossing the Planck's locus given by (u_i,v_i) coordinates. To find out an isotemperature line for the point (u_s,v_s), the two neighbouring adjacent fixed isotemperature lines should be determined at first. It is done by calculating the distances to all of the 31 given lines and picking two adjacent ones of which the ratio between the distances from the point to them is negative ($d_i/d_{i+1} < 0$ as one of the distances is negative and the second is positive). The formula for calculation of the distance between a point and a line is given by

$$d_i = \frac{(v_s - v_i) - t_i(u_s - u_i)}{(1 + t_i^2)^{1/2}}. \tag{8}$$

In the next step, the colour temperature of the point (u_s,v_s) is approximated from the ratio between the distances from the point to each of the neighbouring isotemperature lines. The approximation is done on the assumption that

- the Planck's locus of a black body between the adjacent isotemperature lines (T_i and T_{i+1}) is approximated by a circular arc.
- colour temperature presented in reciprocal scale $TR = 10^6/T$ is a linear function of its position on this arc.
- the angle between adjacent isotemperature lines is small, so a ratio of the arc lengths between the two fixed and the point's isotemperature lines can be approximated by a ratio of distances from the point to the two adjacent isotemperature lines.

The formula for resulting colour temperature is given as

$$TR_c = TR_i + \frac{d_i}{d_i - d_{i+1}}(TR_{i+1} - TR_i). \tag{9}$$

5. Conclusions

In the article, the algorithm for estimation of colour temperature of image is presented. The purpose of the estimation is to render human visual perception of this colour feature in static images as well as in moving ones (video sequences). Thereby, it is a considerable feature of image for application in image search and retrieval tasks. That is just what was a need, and a motivation for its designing origin. MPEG-7, a standard for describing an image content, have got a contribution, proposing a descriptor for visual content browsing based on colour temperature. Other possible application of the colour temperature feature may be conversion of colour temperature of image. Users of multimedia systems often have their personal preferences on colour temperature of viewed images. If the colour temperature of image is known as well as the user preference on it, conversion of image appearance can be easy done to conform to user needs. Further, potentially beneficial domain is photography. Knowledge of the colour temperature of photo image makes it possible to do an automatic conversion of it, just to meet user needs.

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