Segmentation of Fine Details in the CIELAB

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ABSTRACT

In the paper, we propose an algorithm of fine details segmentation in the CIELAB system considering the contrast sensitivity. For the search and segmentation algorithm we use a standard formula of the CIELAB color difference together with the weighting coefficients for the coordinates L^*, a^* and b^*. Experimental methods and results of the estimation of weighting coefficients are shown. Applications of the color model and segmentation algorithm are proposed.

Keywords

fine details segmentation, color space $L^*a^*b^*$, contrast sensitivity of human vision.

1. INTRODUCTION

The CIELAB color metric system is nowadays an international standard and is widely used for the estimation of color difference between original and distorted images. The differences are computed as

$$\Delta E = \sqrt{\left((L_2^* - L_1^*)^2 + (a_2^* - a_1^*)^2 + (b_2^* - b_1^*)^2\right)} \quad (1)$$

where (L^*_1, a^*_1, b^*_1) are the color coordinates of the first (original) image and (L^*_2, a^*_2, b^*_2) are the color coordinates of the second image. The value $\Delta E \approx 2.3$ approximately corresponds to the minimum perceptible color difference for the human eye [7, 10].

Color coordinates can be obtained using transformation of primary colors (*RGB*) into the color space (*XYZ*) and then using formulas [8]

$$L^* = 116\, f(Y/Y_n) - 16;$$
$$a^* = 500[f(X/X_n) - f(Y/Y_n)];$$
$$b^* = 200[f(Y/Y_n) - f(Z/Z_n)],$$

where

$$f(t) = \begin{cases} t^{1/3}, if\ t > 0.008856 \\ 7.787t + 16/116, if\ t \le 0.008856 \end{cases}$$

Values of X_n, Y_n and Z_n are the coordinates of the reference white color.

Equal color spaces CIELAB, CIELUV, CIEDE2000 and others are traditionally used for the estimation of the color rendering distortion of the big objects that have inside uniform color distribution. An advantage of such equal color spaces is that the estimation result weakly depends upon the object's color. S-CIELAB system [8] is proposed for the estimation of the color differences of complex objects. It uses spatial preprocessing of image and combines the traditional metric for color differences with the spatial properties of the human vision. It is achieved via preliminary object filtering before the pixel wise comparison. The difference metric of two images is expanded using the space-frequency adaptation and spatial localization blocks, as well as local and general contrast detection blocks [19].

The estimation of color difference using (1) fails with the decrease of object size because it does not take into account the decline of contrast sensitivity in brightness and chromaticity.

In [15, 16] proposed metric to estimate of color contrast fine details in the color coordinate system Wyszecki [18] considering the weighting coefficients of luminance and chrominance:

$$K_{WUV} = 3\sqrt{\left((\Delta W^*)^2 + (\Delta U^*)^2 + (\Delta V^*)^2\right)} \quad (2)$$

where $\Delta W^* = \left(W_o^* - W_f^*\right)/W_{th}^*$ the normalized value of contrast on brightness index and $\Delta U^* = \left(U_o^* - U_f^*\right)/U_{th}^*$, $\Delta V^* = \left(V_o^* - V_f^*\right)/V_{th}^*$ on chromaticity index; W_o^*, U_o^* and V_o^* are the color coordinates of the fine detail from the test image;

W^*_f, U^*_f and V^*_f are the color coordinates of the background pixels; W^*_{th}, U^*_{th} and V^*_{th} are the weighting coefficients determined by the amount of the minimum perceptible color difference (MPCD).

Color coordinate values in brightness index (W^*) and the chromaticity indexes (U^*, V^*) calculated by the formulas [18]:

$$W^* = 25\ Y^{1/3} - 17;$$
$$U^* = 13W^*(u - u_o);$$
$$V^* = 13W^*(v - v_o),$$

where Y is the luminance, changed from 1 to 100; W^* is the brightness index; U^* and V^* are the chromaticity indices; u and v – are the chromaticity coordinates in Mac-Adam diagram [13]; u_o and v_o are the chromaticity coordinates of basic white color with u_o = 0.201 and v_o = 0.307.

Contrast sensitivity decreases with decreasing size of the detail, consequently, the weighting coefficients values in (2) will increase. In general, their values will depend on the brightness of the background, noise, the masking effect, conditions of observation and other [2]. For fine details with sizes not exceeding one pixel the threshold values are obtained experimentally. In particular [16], for fine details of the test table located on a grey background ($70 < W^*_f < 90$) threshold values are approximately $\Delta W^*_{th} \approx 6$ MPCD, $\Delta U^*_{th} \approx 72$ and $\Delta V^*_{th} \approx 80$ MPCD.

The formula (2), unlike the formula (1), does not estimate the color differences between two images, and determines the normalized color contrast of fine details within a single image. If the condition $K_{WUV} > 1$ is satisfied, then the fine detail is distinguished by an eye and the result weakly depends on the color of the fine detail.

Result of research [15] concludes that the application of $W^*U^*V^*$ color space has the following limitations:

1. Values of the weighting coefficients W^*_{th}, U^*_{th} and V^*_{th} greatly depend on the brightness of the background, which makes difficult to carry out the recognition and segmentation of fine details in photorealistic images with adequate results of visual perception.

2. $W^*U^*V^*$ system is now practically seldom applied because there are more effective systems CIELAB, CIEDE2000, S-CHIELAB and other for estimating the color differences [3, 8, 9, 12, 17, 19].

In this paper, we present our research results of the CIELAB system features in the tasks of fine details segmentation.

2. EXPERIMENTAL ESTIMATION OF THE WEIGHTING COEFFICIENTS

Color contrast of the fine details in CIELAB system is computed similar to (2):

$$K_{LAB} = \sqrt{\left((\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2\right)} \qquad (3)$$

where $\Delta L^* = \left(L^*_o - L^*_f\right)/L^*_{th}$, $\Delta a^* = \left(a^*_o - a^*_f\right)/a^*_{th}$ and $\Delta b^* = \left(b^*_o - b^*_f\right)/b^*_{th}$; L^*_o, a^*_o and b^*_o are the color coordinated of the fine detail; L^*_f, a^*_f and b^*_f are the color coordinated of the background; L^*_{th}, a^*_{th} and b^*_{th} are weighting coefficients determined by the amount of the MPCD on the lightness and chromaticity.

For the experimental estimation of the weighting coefficients we developed the test tables with fine details that are located on the uncolored background. Contrast of the fine details was specified separately for each coordinate L^*, a^* and b^*. For the image visualization the bmp format was used; pixel wise transformation from L^* a^* b^* into *RGB* was carried out.

The following methodology was used during the experiment. Test tables with fixed fine details sizes (1 pixel, 2×2 pixels, 3×3 pixels and 4×4 pixels) were used for each experiment. Spatial position and the number of fine details were defined randomly. Background brightness has mean value L^*_f = 50.

Observer via the software interface changed the contrast for the coordinate L^* (a^* or b^*) for the selected table. This contrast was set from zero to some value when the fine details are being determined on the background by observer. At the end, observer fixed his subjective values L^*_{th} (a^*_{th} or b^*_{th}). Table 1 contains mean weighting coefficients values, determined by 20 observers. The reduction of contrast sensitivity characteristic depending on the size of details shows on Figure 1.

δ	L^*_{th}	a^*_{th}	b^*_{th}
> 4	1	3	4
4	1	10	15
3	2	16	20
2	3	20	30
1	6	40	55

Table 1. Dependence of weighting coefficients on the size of the fine detail

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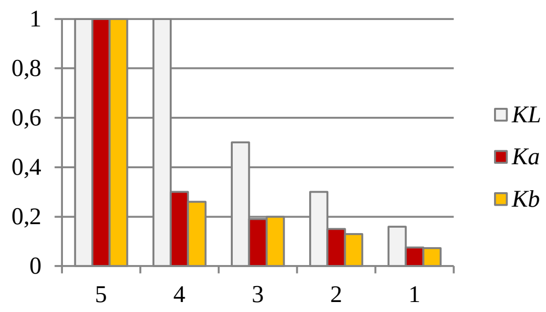


Figure 1. Dependence of the contrast sensitivity from the size of details, where $KL = 1/ L^*_{th}(\delta)$, $Ka = 3/ a^*_{th}(\delta)$ **and** $Ka = 4/ b^*_{th}(\delta)$

The experiments found that while changing the background brightness weighting coefficients vary insignificantly for fine details with size $\delta > 1$. However for the smallest details ($\delta = 1$) the values of the weighting coefficients on the coordinated $\pm a^*$ and $\pm b^*$ are on the border of their range. Question arises - should the color coordinates in the formula (3) be taken into account?

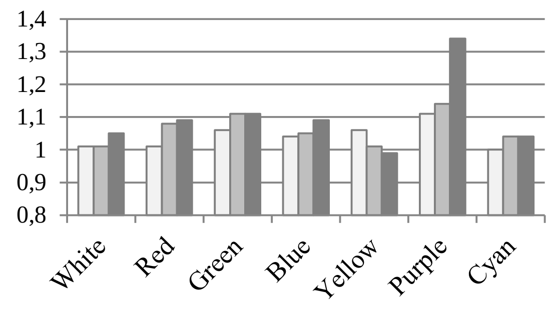
Here we should note that in the photorealistic images the change of the chromaticity coordinates for fine detail without change brightness is extremely rare. Therefore, we find it convenient to consider coordinates a^* and b^* in (3) with obtained weighting coefficients during the estimation of the smallest details color contrast, because they contribute to the final value of contrast.

To confirm the correctness of application of formula (3), series of experiments were carried out. We estimated the threshold values of the contrast of fine details for different colors. Table 2 contains the experimental results for the finest details ($\delta = 1$) for the primary and secondary colors. Dependences of the threshold contrast from the color and background brightness shows on Figure 2.

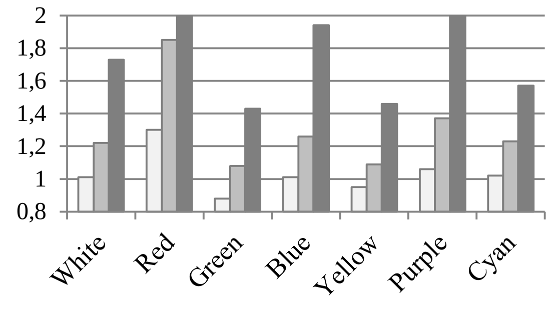
Software interface of the test table used the following functions: setting background brightness (Y_f) in the range 0…255; setting the colors of the fine details in the *RGB* system; changing the contrast of the fine details in *RGB* system relatively to the background; transformation from *RGB* to $L^* a^* b^*$ coordinates and computing the contrast using (3).

Color	*R*	*G*	*B*	L^*	a^*	b^*	K_{LAB}	K_{WUV}	Y_f
white	16	16	16	6.0	0	0	1.01	1.00	150
	15	15	15	6.1	0	0	1.01	1.22	100
	14	14	14	6.3	0	0	1.05	1.73	50
red	27	0	0	-5.1	21.0	8.5	1.01	1.30	150
	29	0	0	-5.2	24.7	10.9	1.08	1.85	100
	40	0	0	-3.3	34.8	22.7	1.09	4.59	50
green	0	24	0	4.6	-25.7	19.6	1.06	0.88	150
	0	23	0	5.0	-25.8	20.3	1.11	1.08	100
	0	20	0	5.2	-23.8	19.8	1.11	1.43	50
blue	0	0	18	-5.8	7.9	-19.0	1.04	1.01	150
	0	0	17	-58	8.4	-19.3	1.05	1.26	100
	0	0	16	-6.0	9.9	-20.3	1.09	1.94	50
yellow	18	18	0	5.9	-6.1	18.7	1.06	0.95	150
	16	16	0	5.7	-5.6	17.7	1.01	1.09	100
	14	14	0	5.6	-5.1	17.1	0.99	1.46	50
purple	30	0	30	-3.6	33.3	-22.3	1.11	1.06	150
	31	0	31	-3.3	36.1	-23.6	1.14	1.37	100
	48	0	48	1.2	48.3	-29.9	1.34	2.95	50
cyan	0	23	23	5.5	-15.2	-5.0	1.00	1.02	150
	0	22	22	5.8	-15.1	-4.8	1.04	1.23	100
	0	19	19	5.9	-13.4	-4.2	1.04	1.57	50

Table 2. Values of the color coordinates and threshold values of the fine detail



a) K_{LAB}



b) K_{WUV}

Figure 2. Dependence of the threshold contrast from the color and background brightness

For the given parameters of the background and contrast observer changed the contrast of the fine details until they do not become distinguishable. At this moment observer fixed contrast value K_{LAB}.

Contrast values K_{WUV} in the $W^*U^*V^*$ system computed using (2) are placed for the comparison.

From the analyses of the results we can conclude that the contrast threshold K_{LAB} insignificantly deviates from one (K_{LAB} = 1) with the change of the background color and brightness. Maximum deviation of the threshold (+0.34) is obtained for the purple fine details on the dark background (Y_f = 50).

Contrast threshold value K_{WUV} in the $W^*U^*V^*$ system significantly depends on the background brightness and has great scatter depending on color of the fine detail with the decrease of the background brightness. Maximum deviation of the threshold (+3.59) is obtained for the red fine details on the dark background (Y_f = 50).

Thus the threshold values of the CIELAB system more accurately correspond to the visual model and the application of the CIELAB system is preferable in the tasks fine details segmentation.

3. ALGORITHM OF FINE DETAILS SEGMENTATION

Description of known methods for search, recognition and object segmentation can be found in [7] and [14].

Fine details can be classified using the following properties: "dot object", "thin line", "texture element". Search for dots and lines are simple algorithms presented in [7]. The most common search algorithm is an image processing using a sliding mask. As an example, for the 3×3 mask the processing is a linear combination of the mask coefficients with the brightness values of the elements, covered with this mask. Image distortions have high influence on the search and recognition of fine details. These distortions appear from the image digital compression and transfer over the noisy channels. The drawbacks of the known algorithms are: a) only brightness value is taken into account, and b) contrast sensitivity of the human vision [2, 17], is not considered at all.

We propose an algorithm of fine details segmentation in images based on the contrast measurement in the uniform color space CIELAB. Consider fine details (δ = 1) segmentation algorithm step by step.

1. Make pixel wise transfer from *RGB* into L^* a^* b^*.

Figure 3. Test image "Man"

2. Select first micro-block using the mask (2×2 pixels) and compute its contrast (3), where $\Delta L^* = \left(L_i^* - L_j^*\right)/ L_{th}^*$, $\Delta a^* = \left(a_i^* - a_j^*\right)/ a_{th}^*$ and $\Delta b^* = \left(b_i^* - b_j^*\right)/ b_{th}^*$; L^*_{th}, a^*_{th} and b^*_{th} are the values of the weighting coefficients from the Table 1 for the fine details with size equal to one pixel; *i* is the pixel number with maximum color coordinates values (L^*_{max}, a^*_{max}, b^*_{max}) and *j* is the pixel number with minimum color coordinates values (L^*_{min}, a^*_{min}, b^*_{min}).

3. Check the condition

$$K_{LAB} > Th, \quad (4)$$

where *Th* is a contrast threshold when the neighbor pixels in the micro-block are distinguished by an eye.

4. If the condition (5) is fulfilled then the decision on membership of the fine details in the micro-block is taken. The micro-block is marked by a marker $m_1(k, i, j) = 1$, where k – micro-block number with spatial coordinates (i, j).

5. If the condition (5) is not fulfilled then the micro-block does not have any fine details that are distinguished by an eye.

6. Slide the mask one pixel forward to the next micro-block and repeat steps 2-5.

Figure 4. Result of segmentation for *δ* = 1
(micro-blocks 2×2; *Th* = 1.5)

After segmentation of the finest details we move to the segmentation algorithm for the 2×2 pixels ($\delta = 2$).

1. Select the first block with the mask 4×4 pixels and divide it into four micro-blocks 2×2 pixels.

2. Check the micro-blocks with marker m_1. If there is from zero to two such micro-blocks then we analyze this block: compute mean value of the color coordinates ($L^* a^* b^*$) for the micro-blocks with $m_1 = 1$ and estimate the contrast using (3), where L^*_{th}, a^*_{th} and b^*_{th} – values of the weighting coefficients from the Table 1 for the fine details with size $\delta = 2$; i – micro-block number with maximum color coordinates values and j – micro-block number with minimum color coordinates values.

3. If number of micro-blocks with marker m_1 is greater than two then slide the mask forward with step equal to two pixels and process the next block.

4. If the condition (4) is fulfilled then mark the micro-blocks using marker $m_2(k, i, j) = 2$ and make segmentation of these micro-blocks.

5. If the condition (4) is not fulfilled then slide the mask forward with step equal to two pixels and process the next block.

Figure 5. Result of segmentation for *δ* = 2
(micro-blocks 4×4; *Th* = 1.5)

Segmentation of the fine details with size of 3×3 and 4×4 pixels can be carried out in similar way.

Figure 6. Result of segmentation for *δ* = 4
(micro-blocks 8×8; *Th* = 1.5)

Selection of the threshold value *Th* in formula (4) depends upon the next factors. It follows from the experimental data (Table 2) that when $K_{LAB} \approx 1$ the fine details (dot objects on the uniform uncolored background) from the test table begin to differ. Contrast of the block depends on the masking effect of the neighbor blocks for the photorealistic images. Thus, we propose to set the threshold value to $Th = 1.5$.

Figure 7 presents test image "Man" and segmented fragments with fine details for $Th = 1$ and $Th = 2$.

a) $\boldsymbol{\delta} = 1$, $\boldsymbol{Th} = 1$

b) $\boldsymbol{\delta} = 2$, $\boldsymbol{Th} = 1$

c) $\boldsymbol{\delta} = 1$, $\boldsymbol{Th} = 2$

d) $\boldsymbol{\delta} = 2$, $\boldsymbol{Th} = 2$

Figure 7. Results of test image segmentation for different threshold values

Thus, the proposed algorithm can segment the fragments of photorealistic images with fine details of a given size considering the contrast sensitivity of the human vision. Additionally, the algorithm allows estimation of the level of fine details (*FDL*) [5, 6] as

$$FDL = 4 \cdot N_{m1}/(W \cdot H),$$

where N_{m1} – number of segmented micro-blocks with 2×2 pixels size; W and H – width and height of the image in pixels.

Experimental results of segmentation algorithm application to the high quality digital images show that it produces adequate output.

If the image is distorted with noises then having low signal to noise ratio (PSNR) leads to identifying the noise components as fine details and the *FDL* value will grow. Artifacts of JPEG or JPEG 2000 compression algorithms with high compression level (low quality) lead to decrease of the *FDL* value due to the blurring of the fine details.

Experimentally we conclude that the *FDL* value changes slightly with PSNR > 41 dB and/or JPEG compression with high quality settings.

4. CONCLUSION

Here we consider an application method of the proposed algorithm in the fine details transfer quality assessment system [1, 4, 9, 11, 17, 19]. For the preliminary quality change compare the *FDL* values of the original (reference) and transformed images after the compression, filtering and other operations. Decrease of the *FDL* value means the definition reduction of the original image.

For qualitative analysis, we offer the following procedure.

1. Apply segmentation algorithm to the original image and receive 4 spatial masks for the regions with fine details: 1 pixel (m_1), 2×2 pixels (m_2), 4×4 pixels (m_4) and more than 4 pixels (m_5).

2. For each selected region with fine details (m_1, m_2, m_4) compute mean deviation of the contrast between original and transformed images (ΔKm_1, ΔKm_2, ΔKm_4) in accordance with the weighting coefficients (Table 1) and formula (3).

3. For the big details and background pixels (m_5) compute mean deviation (ΔKm_5) of the color coordinates in CIELAB system in accordance with the formula (1).

Thus we get the four parameters of color coordinates deviation of original and transformed image. These parameters must be compared with given threshold for visual estimation. We propose to select the threshold value less than 5…10% from the computed values in steps 2 and 3.

Ultimately, the proposed method makes it possible to estimate the reduction of the visual definition by following simple criterion: if the distortion exceeds the threshold, the definition is low; if distortion does not exceed the threshold then the definition corresponds to a high quality.

For dependencies of the visually quality on the selected rating scale from to the parameters (ΔKm_1, ΔKm_2, ΔKm_4 and ΔKm_5) in compression systems (JPEG, JPEG2000, etc.) more research is needed.

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