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Color appearance models CAM16, ZCAM and CAM20u for video applications

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Abstract. This work is devoted to the study of the possibility to use color perception models for processing streaming videos. The paper describes the principles of the control of image parameters which depend on the image adaptive properties. Methods for obtaining adaptive parameters such as brightness of adaptation, brightness of stimulus and brightness of background, as well as observation conditions are described. The CAM16 color perception model is accepted as the main one as well as the ZCAM and CAM20u models as the promising ones. The usability of color perception models is estimated, namely, the change of color rendering vector is assessed. It is shown that the chromaticity points that make up the color tone lines have a different nature of change – slope, shape. The estimates of the dependence of transmitted colors on lightness are provided. It is demonstrated that the lightness parameter is more non-linear character CAM20u as compared to the previous models.

Keywords: image, color space, image quality, CAM16, ZCAM, CAM20u, video rendering.

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1. Introduction

Video quality has been a major concern since the advent of video systems. Today, the emergence of digital television, cinema and computer vision systems imposes new requirements on the quality of transmitted video [1]. To fulfil these requirements, a number of issues that impede the possibility to achieve high video quality should be addressed. The main issues are presented in [2]. The authors of this work state that traditional understanding of color rendering as the main indicator of complex quality cannot provide the quality required at a given moment. That is why two understandings of color transfer, namely the "narrow" and the "wide" one, are proposed in [2]. At this, "wide" understanding means use of the adaptive properties of vision to describe, transfer and assess quality.

In [3, 4], the need for a new approach to the formation, transmission and reproduction of video signals is discussed. The authors suggest proposals based on color perception models that help to reproduce colors with subtle differences on the screen. In particular, they focus on color perception models CAM02-UCS and CAM16.

Development of color perception models is a continuous process. Emergence of ZCAM model [5, 6] led to simplification of the use a color appearance model due to the decrease of analytical expressions, and as a result – the complexity of the system. However, application of such models in video systems is not studied, only the description of the region of transmitted colors is presented in [7].

The color perception model CAM20u [8] is an improved version of previous models that covers unrelated colors. This is very important, since the dynamic range in terms of brightness is limited and the description of these colors is extrapolated. First, an improved model can be provided with the appearance of new test color sets, namely Derby, Gent and ZJU. At this, however, the question on the correlation of the analytical

Table 1. Distinctive analytical features of the models CAM16 and CAM20u.

Parameter	Model CAM16	Model CAM20u
hue quadrature	H	$H = H_{un}$
achromatic signal	$A = \left(2R_a + G_a + \frac{B_a}{20}\right) \cdot N_b$	$A_{un} = A + C_A + A_s$ where $A_s = (2.26Y)^{0.42}$ is the rod contribution and C_A is a function of the logarithms of both tristimulus value Y and angular subtense θ.
colorfulness	$M = C \cdot F_L^{0.25}$, where F_L is the parameter of luminance adaptation and C is the chromaticity parameter.	$M_{un} = C_M \cdot M$ $C_M = (4.4939 - 1.2215d)(4.3615 + 0.7656f)$ $d = \log 10(Y)$, $f = \log 10(\theta)$

framework of proposed model with the ones of previous models remains unanswered. The aim of this work is to analyze the existing models of color perception and find the optimal model in terms of color reproduction to be used in video systems.

2. Comparative analysis of color perception models CAM16 and CAM20u

The model CAM16 [9] based on the averaged data obtained by Prof. M.R. Luo is applicable to only a limited range of colors, while the model CAM20u [8] encompasses unrelated colors as well. The main distinctive analytical features of these two models are presented in Table 1.

It can be seen from Table 1 that the hue quadrature, achromatic signal and colorfulness are substantially different in both models. These differences make corrections to the coordinates of the region of the existence of colors, which influences on the color quality estimates. Figs 1 and 2 show the changes of color coordinates in the coordinate system a_M, b_M, where a_M is the green-magenta axis and b_M is the yellow-cyan axis, respectively. Note that the unevenness is caused not by distortions or changes of the parameters of visual apparatus but only a refinement of the non-linearity and adaptability of vision perception. The refinements are expressed by the parameters C_A and C_M, the values of which are calculated using the polynomials presented in Table 1. Calculations of polynomials use the logarithm of lightness range (d) and the angle of view (f), which change with the distance from observer to the object under consideration as well as with the object size. The value of the angle of view for television is set to 10°, while for other applications it can be in the range of 1…10°.

To ensure objective assessment of the proposed refinements, the assessment using color tone lines was chosen. The peculiarity of this approach is the estimation of both low-saturated colors and monochromatic ones. The number of wavelengths of monochromatic colors is selected based on the number of primary and additional to the primary colors in the ultra-high definition television triangle [10]. Wavelengths of 380, 515 and 700 nm were chosen as the main of television triangle monochromatic colors, while for more detail assessment

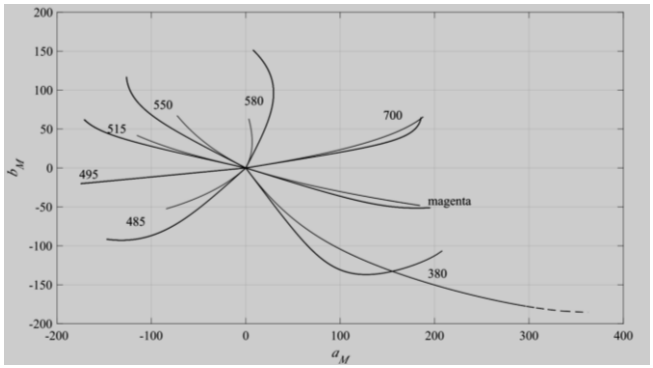

Fig. 1. Comparison of the coordinates of color tone lines in the CAM16-UCS and CAM20u models.

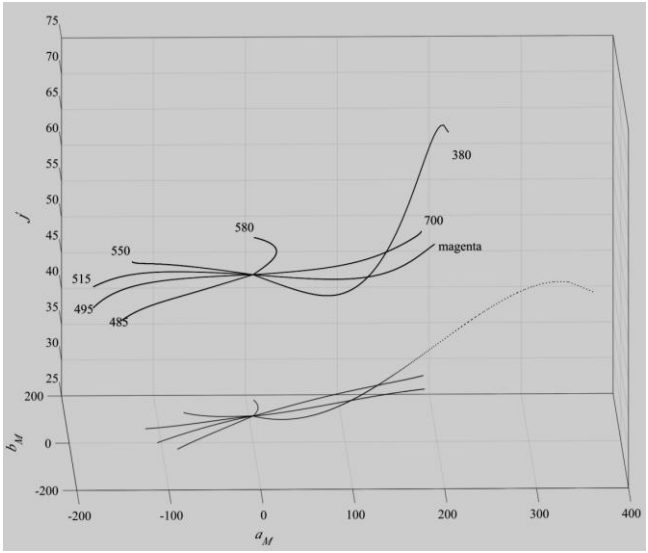

Fig. 2. Three-dimensional representation of the coordinates of color tone lines.

Table 2. Quantitative estimates of the characteristics of the monochromatic colors of selected wavelengths in the CAM16-UCS and CAM20u models.

λ, nm	a_M	b_M	a_{M_CAM20u}	b_{M_CAM20u}	ΔE
380	362.5835	–185.4624	208.0935	–106.4404	174.6501
485	–84.4340	–52.4642	–147.3074	–91.5315	76.4850
495	–104.7551	–12.0525	–174.5763	–20.0857	72.8486
515	–115.3818	41.8350	–170.9937	61.9987	62.1937
550	–72.7965	67.3081	–126.3973	116.8677	75.5513
580	3.2236	63.2272	7.7221	151.4616	90.5326
700	188.0104	65.7392	185.7261	64.9405	20.3079
900	184.5104	–48.1921	195.3108	–51.0130	23.1902

Table 3. Quantitative estimates of the characteristics of the monochromatic colors of selected wavelengths in the $CAM16-UCS$ and $ZCAM$ models.

λ, nm	a_M	b_M	a_{M_ZCAM}	b_{M_ZCAM}	ΔE
380	362.5835	–185.4624	346.4317	–208.7605	28.3493
485	–84.4340	–52.4642	–48.5025	–54.6797	35.9997
495	–104.7551	–12.0525	–85.3157	–4.6009	20.8186
515	–115.3818	41.8350	–94.9878	40.3256	20.4498
550	–72.7965	67.3081	–65.0752	54.3095	15.1189
580	3.2236	63.2272	–6.8776	59.5796	10.7396
700	188.0104	65.7392	123.7143	36.6480	70.5711
900	184.5104	–48.1921	172.3230	–67.4689	22.8064

added the additional monochromatic yellow colors with wavelength 550 and 580 nm, and cyan colors – 485 and 495, as well as magenta color.

It can be seen from Fig. 1 that the area of blue colors is subject to significant changes, where perceptual color differences are small. It can see that the line corresponding to the wavelength of 380 nm has a bend in the model CAM20u as compared to the model CAM16-UCS. Moreover, the area of cyan, green and yellow colors became more elongated, which indicates an expansion of the area of color differences. The areas of red and magenta colors remain unchanged. Fig. 2 shows three-dimensional representation of the coordinates of the lines as the functions of lightness.

A distinctive feature of the model CAM20u is the appearance of the nonlinearity of color tone lines as the functions of lightness (J) for example green, blue and yellow colors. There is also a slight change in lightness for the coordinates of the top red and magenta regions. The area of blue colors versus lightness parameter is significantly different in the model CAM20u as compared to that in the model CAM16-UCS. Table 2 presents the estimates for monochromatic colors, since their differences in both considered models are the largest. These estimates are presented in CIE units (ΔE), expressed as the length of the vector in three-dimensional space. The criteria for evaluation of vector length are provided in [11–13].

3. Comparative analysis of the color perception models CAM16 and ZCAM

In [14], a promising model that enables to take into account the adaptive properties of vision is proposed. This model enables to greatly simplify the use color appearance model due to a decrease in the analytical expressions. Its distinctive feature is the coverage of a larger dynamic range of brightness. Fig. 3 and Table 3 show the comparison of the estimates for the selected colors in the CAM16-UCS and ZCAM models.

It should be noted that the differences in coordinates in the latter two models are much smaller as compared to those in the CAM16-UCS and CAM20u models. Nevertheless, these differences are enough large to be classified as unacceptable. Typical changes in color tone

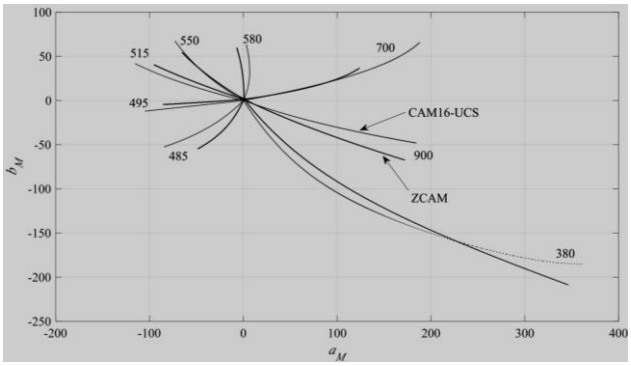

Fig. 3. Comparison of the coordinates of color tone lines in the CAM16-UCS and ZCAM models.

lines are observed for all wavelengths except for 550 and 700 nm. And the area of the chromaticity diagram in the coordinates of the ZCAM model is less than that in the coordinates of the CAM16-UCS model, which can be seen from Fig. 3.

4. Conclusion

Estimates of color perception models are important due to the fact that their diversity is currently large, and each is intended to perform certain tasks, at the same time, it should be understood which one is most suitable for video applications.

The study carried out in this work demonstrates that the ZCAM and CAM20u models, which are both the modified CAM16-UCS model, currently exist. It may be concluded from the result presented in Figures 1 and 3 that the area of existing colors, which is described by the line of monochromatic colors, significantly changes if a different model is used. The quantitative estimates presented in Tables 2 and 3 show that the changes color coordinates with respect to the values obtained in the CAM16-UCS model are greater in the CAM20u model as compared to the ZCAM one. However, the values of the changes of the coordinates of colors expressed by the vector of distance into color space between two colors (ΔE), (more than 10 CIE units) are unacceptable for an observer, as may be concluded based on the data presented in Tables 2 and 3.

The lines of color tones are also different in different models. The nature of their differences is shown in Figs 1–3. The amount of change for different hue lines will be different. These changes will be much smaller near the white point than near the coordinate of monochromatic colors.

The area in the CAM16-UCS space is slightly larger, while the area in the space CAM20u is the largest. This fact explains different color differences for each area of color locus. Taking into account these features, we recommend to use the CAM20u model for video applications as it comprises the largest number of variative parameters and covers the unrelated color area.

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Volodymyr V. Pyliavskyi: investigation, resources, writing – review & editing.
Bashar Sami Bashar: resources, validation, writing – review & editing.
Marwa moutaz Ismail: resources, writing – review & editing.

Кольорові моделі CAM16, ZCAM і CAM20u для відеозастосувань

N. Raheem, A.Q. Taher, A.I. Alanssari, B.B. Пилявський, B.S. Bashar, M.M. Ismail

Анотація. Дана робота присвячена вивченню можливості використання моделей сприйняття кольору для обробки потокового відео. Описано принципи керування параметрами зображення, які залежать від адаптивних властивостей зображення. Описано методи отримання таких адаптивних параметрів, як яскравість адаптації, яскравість стимулу та яскравість фону, а також умови спостереження. Модель сприйняття кольору CAM16 прийнята як основна, а моделі ZCAM і CAM20u – як перспективні. Оцінено зручність використання моделей сприйняття кольору, а саме зміну вектора передачі кольору. Показано, що точки кольоровості, з яких складаються лінії колірного тону, мають різний характер зміни – нахил, форму. Наведено оцінки кольорів, що залежать від світлоти. Продемонстровано, що параметр світлоти кольору має більш нелінійний характер CAM20u порівняно з попередніми моделями.

Ключові слова: зображення, колірний простір, якість зображення, CAM16, ZCAM, CAM20u, рендеринг відео.