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PROBLEM QUESTIONS OF TV COLORIMETRY

GOFAIZEN O., PILYAVSKII V.

Odessa National A. S. Popov Academy of Telecommunications
SE "Ukrainian Research Institute of Radio and TV"
1 Kovalska St., Odessa 65029, Ukraine.
oleg.gofaizen@gmail.com, v.pilyavskiy@ukr.net

ПРОБЛЕМНІ ПИТАННЯ ТВ КОЛОРИМЕТРІЇ

ГОФАЙЗЕН О. В., ПИЛЯВСЬКИЙ В. В.

Одеська національна академія зв'язку ім. О. С. Попова
ДП "Український науково-дослідний інститут радіо і телебачення"
65029, Україна, м. Одеса, вул. Ковальська, 1.
oleg.gofaizen@gmail.com, v.pilyavskiy@ukr.net

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ГОФАЙЗЕН О. В., ПИЛЯВСКИЙ В. В.

Одесская национальная академия связи им. А. С. Попова
ГП "Украинский научно-исследовательский институт радио и телевидения"
65029, Украина, г. Одесса, ул. Кузнечная, 1.
oleg.gofaizen@gmail.com, v.pilyavskiy@ukr.net

Abstract. The analysis of problematic issues that have arisen in the process of drafting the ITU Handbook "TV colorimetry" and the ITU Report "Elements of TV colorimetry" conducted by WP 6C ITU-R, in which the authors are actively involved. The data of presented analysis can be used in subsequent stages of development the drafts of these international documents, and in any studies in the field of TV colorimetry

Key words: CIECAM02, CAM02-USC, iCAM, iCAM06, color appearance model, color fidelity, transmitted and reproduced color gamut, CMFs, color rendering, end-to-end video path, TV colorimetry, uniform color space

Анотація. Представлено аналіз проблемних питань, що виникли в процесі розробки проектів Довідника МСЕ "ТВ колориметрія" й Звіту МСЕ "Елементи ТВ колориметрії", що їх проводить РГ 6С МСЕ-Р, в якій автори приймають активну участь. Дані представленого аналізу можуть бути використані в наступних етапах розробки проектів цих міжнародних документів, а також у будь-яких дослідженнях у сфері ТВ колориметрії

Ключові слова: кольоропередача, модель кольоросприйняття, наскрізний відеотракт "від світла до світла", область передаваних та відтворюваних кольорів, рівноконтрастний колірний простір, ТВ колориметрія, удільні координати кольорів, CIECAM02, CAM02-USC, iCAM, iCAM06

Аннотация. Представлен анализ проблемных вопросов, возникших в процессе разработки проектов Справочника МСЭ "ТВ колориметрия" и Отчёта МСЭ "Элементы ТВ колориметрии", проводимой РГ 6С МСЭ-Р, в которой авторы принимают активное участие. Данные представленного анализа могут быть использованы на последующих этапах разработки проектов этих международных документов, а также в любых исследованиях в сфере ТВ колориметрии

Ключевые слова: цветопередача, модель цветовосприятия, сквозной видеотракт "от света до света", область передаваемых и воспроизводимых цветов, равноконтрастное цветовое пространство, ТВ колориметрия, удельные координаты цветов, CIECAM02, CAM02-USC, iCAM, iCAM06

INTRODUCTION

Over several years, ITU-R Study Group (SG) 6 conducts the drafting of international ITU-R Handbook "TV colorimetry" by the decision of the Working Party (WP) 6P [1] on the plan adopted by the WP 6J [2]. At the moment this work performs WP 6C. Development is being held on the initiative of Ukraine and on the basis of studies in the field of TV colorimetry, conducted in Ukraine.

This development is a complex and multidimensional, and it became clear that this devel-

opment and the relevant international discussion would require more significant efforts. Therefore, WP 6C came to decision [3] on development of the draft ITU-R Report "Elements of TV Colorimetry", the content of which is based on the same information base as the content of the draft Handbook.

This article is devoted to the analysis of problem issues encountered during development of these documents, data of which can be used in subsequent stages of the development of these international documents, and any studies in the field of TV colorimetry.

POSSIBLE DEFINITION OF NOTION "TV COLORIMETRY"

International documents contain such definitions related to notion "TV Colorimetry"

In the Chapter 845 "Lightness" of International Electrotechnical Vocabulary [4] the definition of the term "colorimetry" (definition 845-05-10) is done as:

"Measurement of colors based on a set of conventions".

In the Chapter 723 "Radio and Television Broadcasting" of International Electrotechnical Vocabulary [5] the definition of the term "colorimetric system" (definition 723-08-41) is done as:

"The set of three primary colors and a reference white".

In other sources (for example http://en.wikipedia.org/wiki/Colorimetry [6]):

"The science and technology used to quantify and describe physically the human color perception".

Based on these definitions, as well as on used the term "Colorimetry" in ITU-R Documents, for notion "TV Colorimetry" could be proposed such definition:

"The branch of colorimetric science and technology relative to TV systems design and to TV color rendering assessment"

It follows that the issues of TV Colorimetry could be defined as such:

– Definition of TV system main characteristics based on the selection of colorimetric system and of signal transformations that affect on color rendering.

– Fidelity of color rendering assessment with consideration of taking place restrictions and simplifications.

USING THE CONCEPT "TV COLORIMETRY" IN THE NARROW AND BROAD SENSE

The concept "TV Colorimetry" in the narrow (classic) sense could be associated with color rendering without consideration of spatial characteristics of image and of image perception. Within the framework of this definition characteristics of television system are considered only from point of view of TV image large detail color rendering and of luminance halftones transmission characteristics.

Such approach is limited, as for this spatial characteristics of image transmission and human perception are not considered, but assessment of color rendering is general enough independently on spatial characteristics of transmission and of mage perception.

The concept "TV Colorimetry" in the broad sense i.e. with consideration of spatial properties of image and of its perception is outside of classic definition of colorimetry, because vision perception model in this case is not limited by color appearance model, but most probably it is image perceptual model including properties of color appearance together with spatial characteristics of image perception.

Use of this concept, in particular, allows to evaluate

– color rendering fidelity of real scenes, with this assessment will be specific for each particular scene;

– image distortion associated with the effect of specific factors that are critical with respect to specific types of color distortion, in particular, the sampling of the color difference signals, color distortion of the image transitions associated with non-constant luminance principle of image trans-

mission, possible other types of distortions associated with a variety of signal processing algorithms.

FIDELITY OF COLOR RENDERING IN LIGHT-TO-LIGHT TV SYSTEM PATH

Colour rendering quality assessment has to be realized from viewer's point of view, and this means what assessment must be applied for TV system light-to-light video path, i.e. subject is comparison of natural scene color objects with reproduced image objects which could be realized by comparison scene object uniform color space coordinates $S_{1\,\mathrm{Obj}}, S_{2\,\mathrm{Obj}}, S_{3\,\mathrm{Obj}}$ and reproduction image coordinates $S_{1\,\mathrm{Img}}, S_{2\,\mathrm{Img}}, S_{3\,\mathrm{Img}}$.

Determining the distance between points of colors in the uniform color space and comparing it with the distance corresponding to the color discrimination threshold levels or color differences corresponding to a given level of image quality it is possible to judge the quality of color rendition quantitatively.

UNIFORM COLOR SPACES WHICH MAY BE USED FOR COLOR RENDERING ASSESSMENT

If come from use of concept "TV Colorimetry" in narrow sense, i.e. realize assessment of color objects rendering fidelity without spatial characteristics of image and of image perception, that then for assessment of color rendering fidelity in TV systems most perspective could be uniform color spaces, specified by CIE: CIELUV [7], CIELAB (L^*, a^*, b^*) [7], CIECAM02 (J, a_M, b_M) [8] and CIECAM02 model modification's CAM02-UCS (J', a'_M, b'_M) [9].

Metrics of CIELUV and CIELAB systems is built without consideration of influence of image viewing conditions on the perceived object colors. In these systems conditions of not distorted color rendering are formulated as such:

$$L^*_{\mathrm{Img}} = L^*_{\mathrm{Obj}}; \quad u^*_{\mathrm{Img}} = u^*_{\mathrm{Obj}}; \quad v^*_{\mathrm{Img}} = v^*_{\mathrm{Obj}};$$

$$L^*_{\mathrm{Img}} = L^*_{\mathrm{Obj}}; \quad a^*_{\mathrm{Img}} = a^*_{\mathrm{Obj}}; \quad b^*_{\mathrm{Img}} = b^*_{\mathrm{Obj}}.$$

Metrics of CAM02-UCS system is addition to CIECAM02 system and depends on human perception adapting luminance $L_{\mathrm{A\,Obj}}$ and $L_{\mathrm{A\,Img}}$ and on viewing conditions VC_{Obj} and VC_{Img} on the shooting side and on the reproduction side which can be varied in a wide range independently. So, in this metrics not distorted color rendering may be formulated as such:

$$J'_{\mathrm{Img}}\Big|_{L_{\mathrm{AImg}}, VC_{\mathrm{Img}}} = J'_{\mathrm{Obj}}\Big|_{L_{\mathrm{AObj}}, VC_{\mathrm{Obj}}}; \quad a'_{M\,\mathrm{Img}}\Big|_{L_{\mathrm{AImg}}, VC_{\mathrm{Img}}} = a'_{M\,\mathrm{Obj}}\Big|_{L_{\mathrm{AObj}}, VC_{\mathrm{Obj}}}; \quad b'_{M\,\mathrm{Img}}\Big|_{L_{\mathrm{AImg}}, VC_{\mathrm{Img}}} = b'_{M\,\mathrm{Obj}}\Big|_{L_{\mathrm{AObj}}, VC_{\mathrm{Obj}}}.$$

This means that not distorted color rendering will be only in systems, adaptive to viewing conditions, main principles of which realization are specified in Recommendations ITU-R BT.1691 [10] and ITU-R BT.1692 [11]. Work [12] presents the examples of color rendering distortion estimations and shows that in dependence on relation of luminance adaptation and viewing conditions at the transmitting and receiving places, color distortion will vary between invisibility level to inadmissible level.

Evaluation of color rendition fidelity for systems with extended dynamic luminance range (EDR), including video information systems, EDR TV systems, et al., is related with use of color appearance models, covering a range of luminance several times larger than the luminance of 1000 cd/m^2, which is close to the upper end of the range of luminance, in which operates CIECAM02 model for photopic vision, as well as of luminance, at which acts mesopic and scotopic vision. For these parts of range of luminance CIE yet not formalized appropriate models, but progress in this direction takes place, and there are proposals for models of color appearance, that can be used for quantitative estimates [13-16]. Among them, to the number of the most perspective models may be referred iCAM06 model [13, 14], use of which for colorimetric estimations in narrow sense is possible if not use transformations related to spatial model properties.

If we start from the use of the sense of "TV colorimetry" in broad sense, i.e., assess fidelity of color rendering, taking into account the spatial characteristics of the image and of its perception, then for color rendering fidelity in TV systems evaluation among the most promising models are iCAM [17] and iCAM06 that are models of color vision of new generation, the further development and adoption of which as universal models will take years [18].

However, the use of these models in a study on the evaluation of color rendition fidelity in modern and new TV systems can provide a greater effect than any other approach, as embodied the achieved level of world progress in this area.

In this formulation conditions for undistorted color rendition will depend additionally on the spatial characteristics of the object.

ACCOUNTING FOR THE SPECTRAL CHARACTERISTICS OF PERCEPTION

There are currently two systems of colour coordinates, based on colour matching functions (CMFs) adopted by CIE, which can be used for any application including television:

- CIE 1931 [19];
- CIE 2006 [20].

CIE 2006 system is more accurately expressing the spectral characteristics of human cone vision compared to CIE 1931.

Practically all colorimetric standards and existing colorimetric data are based on CIE 1931 system including standards for TV applications. Therefore it is difficult to imagine that in the next few years this system will come out of use.

However, with the adoption of the CIE 2006 system and the wish to obtain more stringent colorimetric assessment and thereby make more sophisticated technical solutions, including in the field of TV applications, the transition to the use of this system is the real trend of TV colorimetry progress.

Imperfection of CIE 1931 system was found by Sony corporation [21] when comparing the CRT-based displays and OLED-panels, and it was found that there may be noticeable color shift.

Considering the progress of TV systems, aimed to further empowering TV technology and improving the quality of the image, we can predict that the problem of the transition to the CIE 2006 system will be implemented.

For CIE 2006 could be the normative basis for normative provision of new generations of TV systems, it would be necessary to standardize the colorimetry of old TV systems in the coordinates of CIE 2006 system which as far as possible to exactly match the colors, the coordinates of which are defined in the system CIE 1931. This is only possible for a certain spectral composition of screens luminescence (for example, based on the spectral characteristics of OLED-panels), which for this purpose should be standardized. In this case, would be strictly standardized systems colorimetry for the case of new panels and provided approximate use of older displays colorimetry.

At the same time there is also the problem of creating modified versions of used systems CIELUV, CIELAB that CIECAM02, as well as promising new systems such as iCAM and iCAM06, which should be based on the use of color space CIE 2006, what would correspond to increase rigor of colorimetric assessments.

EVALUATION OF COLOUR GAMUT TRANSMITTED AND REPRODUCED BY TV SYSTEMS

Area of transmittable color gamut is a characteristic of the TV system that determines the boundaries within which color rendition is possible. The Report ITU-R.2246-3 [22] shows the possible ways of expanding the area of colors that can be transmitted by TV system. Characterization of the transmitted and reproduced color gamut can be given at different levels:

– if it is needed to characterize the possibility of color rendering without considering the real metric of color perception, it is enough to use systems CIE 1931 or CIE 2006, but color repro-

duction area is characterized qualitatively, but not quantitatively, because color space of these systems is non-uniform in relation to human perception;

– if it is needed to take into account the metric of human perception, but to abstract from the taking into account image viewing conditions, uniform color space of color appearance systems adopted by CIE in 1976 – CIELUV and CIELAB – can be used, but estimates do not reflect the real conditions of color scene perception, i.e., the change of perceived color gamut with changing image viewing conditions;

– if it is needed to take into account human perception metric considering the conditions of viewing, it becomes possible to evaluate and compare the possibilities of color transmission and reproduction, taking into account viewing conditions on the transmitting and receiving sides, and therefore to judge not only on the shifts of the individual colors, but also on the change the color gamut available to the observer, due to changes in the relationship between the viewing conditions at scene shooting point and viewing conditions at image reproduction point.

Examples of relevant evaluations are presented in [23, 24].

CONCLUSION

1 Definition of television colorimetry is composite, since it determines the use of the branch of science and technology, implemented with regard to the colorimetric characteristics of TV systems and their evaluation. The proposed definition in this article may be used as a working, but in any case it is related a combination of two problems − the specification of TV systems and evaluation of color fidelity in a through light-to-light video path. Apparently this definition it is advisable to proceed with the development of any documents related to the colorimetric aspects of television.

2 In dealing with description or standardization colorimetric characteristics of TV systems and related video applications it is needed to proceed from the sense in which it is wanted to use colorimetry − only in relation to the characteristics of color reproduction of large parts of the scene or also applied to color distortion, depending on the spatial structure of the image associated with the principles of design and implementation of TV systems, such as systems that perform or not perform the principle of constant brightness, systems that use sampling color difference signals, and others. Accordingly, when addressing issues of preparation of reports, manuals and other documents devoted TV systems colorimetry it should be decided in what proportion should be used colorimetry in a narrow or broad sense.

3 Quantitative evaluation of color fidelity in the TV system is available only when used uniform color space having the Euclidean metric. The closer to the Euclidean metric, the more perfect will be assessed color rendering quality. Currently known uniform color spaces embody different levels of interpretation of the available in the world experimental data, and their use can be carried out at the level of compromise between their availability and versatility, the degree of compliance with the available experimental data on the characteristics of color appearance for varied over a wide range conditions of the image viewing applicable to images with a complex structure and a variable range of possible changes in luminance.

4 If we take as a basis for evaluation of color rendering without taking into account the conditions of image perception, then for this purpose can be used, for example, color appearance models CIELUV and CIELAB. These models are relatively simple, widely used in the world for different applications including television, but they not accurately reflect the properties of color appearance and refer to fixed conditions of perception, which were obtained by the experimental data underlying these systems. Nevertheless, the lack of accounting viewing conditions allows to use these models as a more universal way of compromise in relation to the limited accuracy.

5 Using the model CIECAM02 together with the CAM02-UCS allows to evaluate the color rendering fidelity with maximum currently available accuracy, taking into account that this model is based on current knowledge of the mechanisms of visual perception and the amount of experimental data available at the moment. This model takes into account the conditions of adaptation of viewing perception, and therefore can be used to build adaptive applications and for a more accurate assessment of color rendition fidelity. But this assessment should be carried out for the given conditions

of adaptation, which in some cases lead to increase the volume of evaluations. The use of possibilities to adapt to the conditions of perception can lead to a new level of quality of color reproduction.

6 With the introduction of TV systems with ultra-high dynamic range of brightness problem of evaluation the color rendering fidelity should be based on the model of color appearance, based on the description of the mechanisms of perception and experimental data covering this range. These models include, for example, the model iCAM06, which, despite the need for further research in this area, embodies the current state of knowledge about color perception in the range of brightnesses, covering a range of photopic, mesopic and scotopic vision, and its use would allow to evaluate the color rendition quality over the entire range of brightness, which can be calculated similar systems. In this case, it appears that it would be advisable to exercise the assessment of colour rendition fidelity as a whole and separately for traditional levels of brightness, for very low and very high brightness. It should be noted that this model is a development of CIECAM02 model, and because it is adaptive and has all the features inherent in the model CIECAM02. This model is built taking into account both colorimetric and spatial properties of perception, and therefore is universal in terms of the use of colorimetry in a narrow and in a broad sense.

7 In order to CIE 2006 could be the normative basis of normative provision for new generations of TV systems, it would be necessary to standardize the colorimetry old TV systems in the coordinates of CIE 2006 system, which as far as possible exactly match the colors, the coordinates of which are defined in CIE 1931, which is only possible for a certain spectral composition of the luminescence screens (e.g., based on the spectral characteristics of OLED-panels), which for this purpose should be standardized. In this case, would be strictly standardized colorimetric systems in the case of new panels reproducing provided approximate use colorimetry of older displays. At the same time there is also the problem of creating modified versions of operating systems CIELUV, CIELAB that CIECAM02, as well as new advanced systems, such as iCAM that iCAM06, which should be based on the use of CIE 2006 color coordinates system, which would correspond to the increase in the precision of colorimetric evaluations.

8 Color gamut that can be transmitted and reproduced by TV systems is determined primarily by the limitations associated with the choice of a colorimetric system on transmitting and receiving sides. If digital signal processing will not limit this area, the area of transmitted and the reproduced color gamut is the intersection of the areas defined for the transmitting and receiving sides. Presentation of transmitted color gamut in uniform color space would show how we can implement in a TV color system possibilities of color gamut transmission from the point of view of the observer, what is very important taking into account that the uniform color space metric is essentially nonlinear with respect to the traditional XYZ system used or to the signal space RGB. Presentation of the field transmitted and reproducible color gamut in a space is a problem, because the three-dimensional view of the whole volume of colors will be integral, but it is very difficult to judge quantitatively, and presentation in the form of projections allows us to observe the conformities, but in a more cumbersome form, apparently a compromise in this regard matter for the future.

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