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THE RESULTANT IMAGE QUALITY IN THE LIGHT-TO-LIGHT VIDEO PATH OF INFOCOMMUNICATION APPLICATIONS

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РЕЗУЛЬТИРУЮЩЕЕ КАЧЕСТВО ИЗОБРАЖЕНИЯ В СКВОЗНОМ ВИДЕОТРАКТЕ ИНФОКОММУНИКАЦИОННЫХ ПРИЛОЖЕНИЙ “ОТ СВЕТА ДО СВЕТА”

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Abstract. *An analysis of the problem of image quality assessment and management in light-to-light video transmission path of infocommunication applications is presented. The possibilities for further image quality enhancement and image quality evaluation are pointed out and suggestions for their implementation are made.*

Аннотация. *Представлен анализ проблемы оценки качества и управления качеством изображения в сквозном видеотракте “от света до света” систем изображения. Отмечены возможности дальнейшего повышения качества изображения и совершенствования методов оценки качества изображения и вносятся предложения по их реализации.*

I. INTRODUCTION

Modern progress of video technology has led to the availability of a wide range of imaging systems from simple multimedia applications to digital cinema systems, UHDTV systems and 3D-TV systems.

The purpose of the progress of modern image systems is striving to realize the optimum image quality, which corresponds to the maximum realization of system capabilities at the current level of technology available within the resource identified by limited complexity and cost of implementation of image production and reproduction systems, and the limited bandwidth of the transmission channel.

The realization of this goal is defined, on the one hand, by the level of the technical solutions adopted, determining the possible realization of the potential level of image quality at the production and post-production, processing, storage, transmission and reproduction stages, on the other hand, by the level of technical equipment operation.

Making optimal decisions is determined by the choice of objects, assessment the quality of transmission and reproduction of which may serve as a representative measure of the video applications quality and image quality criteria characterizing the degree of compliance with the original image transmitted taking into account the nature of visual perception. Thus, effective solutions can be obtained in the case of use the principle of adaptive principle for imaging systems construction in accordance with which the implementation of systems which shall be based on a combination of factors which determine the quality of image transmission that can be effectively implemented in the digital video application paths provided by transmission in part of the digital transmission bit stream corresponding metadata carrying information serving for management by sections of transmission and reproduction path sections [1, 2].

Evident the complexity of image quality assessment and management, aspects of which are discussed in this paper, and new suggestions are made.

II. THE STATISTICAL NATURE OF THE APPEARANCE OF DISTORTIONS AND CAPABILITIES FOR IMAGE QUALITY MANAGEMENT IN DIGITAL IMAGING SYSTEMS

All the variety of images and video sequences, produced and transmitted by different imaging systems has a wide variation of the statistical properties, including the variation of brightness halftone distribution, the variation of colors gamut, variation of detail and of spatiotemporal spectrum of the signal and its components.

Statistical properties of the image features interact with characteristics of the through path of video applications, which may vary within wide limits depending on the construction of the systems of image capturing, production and post-production, compression, multiplexing and reproducing and used image processing algorithms

It should also be taken into account the possible variations of the conditions of image viewing on the transmitting and receiving sides, as well as at points of the image processing and post-processing, which may affect image quality due to changes characteristics of human color appearance.

It can be assumed that the effective image quality management can be achieved if the classification of a set of images and video sequences, which may be the subjects of transfer, processing and reproduction, as well as the classification of types of image transformations in through path of imaging systems .

If relevant metadata descriptors would be entered into bit stream, it will contribute to the possibility of obtaining optimal solutions.

III. CURRENT LEVEL OF VIDEO APPLICATIONS

Modern level of video applications combines videophone and video conferencing applications [3, 4], audio-visual multimedia applications to receive programs on mobile terminals provided for the implementation of limited-definition video systems [5], digital multimedia audio-visual telecommunication systems [6], standard digital television (SDTV) systems [7], high definition television (HDTV) systems [8–10], ultra high definition television (UHDTV) systems [11], stereoscopic television (3DTV) systems [12, 13], digital cinema (DC) systems [14-16], large screen digital imagery (LSDI) systems [17], video information systems [18], as well as multimedia applications that can be implemented at all levels of video applications.

IV. INDICATIONS OF POTENTIAL IMAGE QUALITY IN VIDEO APPLICATIONS

Potential image quality is determined by parameters of the system, which characterize the implementation in which its characteristics difference from the standardized characteristics is as little as possible. For video applications used in broadcast and non-broadcast infocommunication systems, the main characteristics that define the potential image quality, include definition, colorimetry, contrast ratio and halftone transmission characteristics, bit depth of digital signal encoding, compression ratio and bit rate.

Videophone systems and video conferencing systems as defined in Recommendations ITU-T H.100 and ITU-T H.120, which define the two formats, compatible with the formats SDTV and LDTV (with half the number of scan lines)

Characteristics of multimedia applications to receive programs on mobile terminals specified in Recommendation ITU-R BT.1833-2 are designed mainly for the use of the format QVGA (320×240) and WQVGA format with extended horizontal image size.

Characteristics of modern digital multimedia audiovisual communication systems, including systems for the videophone and video conferences are defined in Recommendation ITU-T H.324, which provides formats SQCIF (128×96), QCIF (176×144), CIF (352×288) , 2CIF (704×288), 4CIF (704×576) and 16CIF (1408×1152).

SDTV systems defined in Recommendation ITU-R BT.601-7, are designed for use formats 720×576 and 720×480, and provides for them colorimetry, which corresponds to the coordinates of the primary colors R, G, B $x_R = 0,630; y_R = 0,330; x_G = 0,290; y_G = 0,600; x_B = 0,150; y_B = 0,070$ and the coordinates of reference white D65 coordinates. These coordinates corresponds to a limited transmitted color gamut, defined by triangle of primary colors on the chromaticity diagram.

HDTV systems defined in Recommendations ITU-R BT.709, ITU-R BT.1543 that ITU-R BT.1847, designed for use formats of two levels of 1280×720 and 1920×1080 and colorimetry defined by coordinates $x_R = 0,640; y_R = 0,330; x_G = 0,300; y_G = 0,600; x_B = 0,150; y_B = 0,060$ and basic colors reference white D65, close to colorimetry of SDTV systems.

Two levels of the digital encoding bit depth for SDTV and HDTV systems – 8 bit and 10 bit – are defined

The UHDTV systems specified in Recommendation ITU-R BT.2020, are designed for use in two formats – 4K: 3940×2160 and 8K: 7680×4320 and for extended colorimetry determined by primaries chromaticity coordinates $x_R = 0,640;\ y_R = 0,330;\ x_G = 0,300;\ y_G = 0,600;\ x_B = 0,150;\ y_B = 0,060$ that correspond to the transmitted color gamut, significantly enhanced relatively to all the above systems.

UHDTV systems are based on two versions of forming luminance signal and color difference signals - traditional, inherent to all of the above systems, which does not support the constant luminance principle, as well as that, for which constant luminance principle is performed. Two versions digital video encoding bit depth are specified – 10 bit and 12 bit.

Fig. 1 shows a triangle of primaries of SDTV, HDTV and UHDTV systems on the plane of CIE-31 *x*, *y* coordinates. Fig. 2 shows the projection of the triangle on the coordinate plane of red-green and yellow-blue axes of uniform color space CAM02-USC [19], based on the use of the uniform color appearance model CIECAM02 [20] constructed for the relative brightness of the image details 0.01 relatively to white brightness, for brightness of the white 250 cd/m^2 corresponding to observer adapting brightness 50 cd/m^2 and for average image viewing conditions.

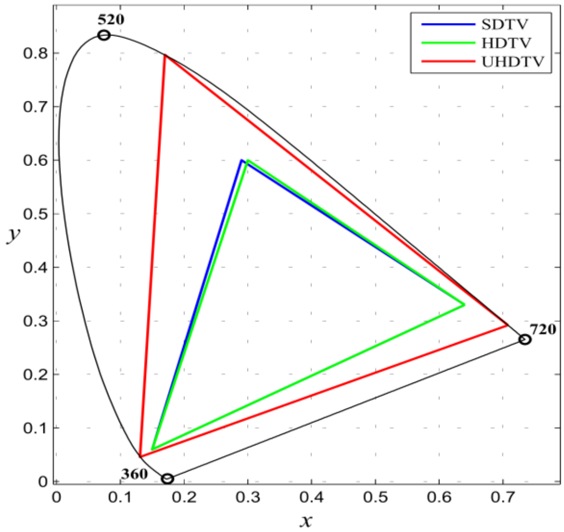

Figure 1 – Color primaries triangle of SDTV, HDTV and UHDTV systems presented on CIE-31 chromaticity diagram x, y coordinates plane

From here the ratio of color gamut transmitted by TV systems of various levels from the point of view of the observer is seen. More complete data of studies in this direction are published in works [21–23].

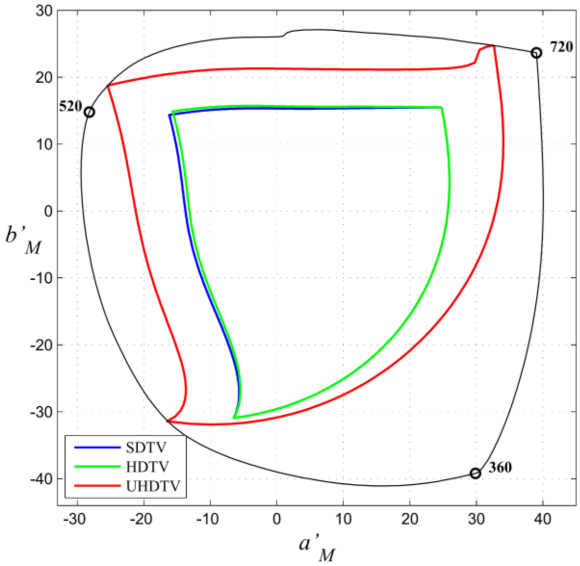

Figure 2 – Projections of color primaries triangle of SDTV, HDTV and UHDTV systems presented on the plane of coordinates of red-green (a'_M) and yellow-blue (b'_M) of uniform CAM-USC color space

Technological progress led to the possibility of practical implementation of the new level of video applications, namely, the systems of electronic production and reproduction of scene images with the number of pixels, close to 2000×4000 (4K) and 4000×8000 (8K), such as digital cinema systems (DCDM), large screen system LSDI (ACES) (which can be used for various applications, as well as digital cinema), with characteristics similar to UHDTV systems. For digital cinema (DC) systems in the world two levels are standardized:

– DCDM system, characteristics of which are defined in version 1.0 of DCI Specification [21], which was later replaced by version 1.2 [22];

– DCDM system, characteristics of which are defined in standard SMPTE 2048-1.

DCI specification defines use of tristimulus values *X,Y,Z* as primary color signals of digital cinema system. Signal *Y* directly carries information about the details of the scene luminance and *X,Z* signals carry chrominance information. In this system, the area of transmitted color gamut covers points of all chromaticities inside the chromaticity diagram for all luminance levels. Thus, there are no restrictions for transmission of any real colors. The second version of the specification defines color gamut, covering all the chromaticity diagram, and thus provides possibility for free choice of the reproduced color gamut for the reproduction system but this function is somewhat limited as compared to the first version of digital cinema specification.

Standard SMPTE 2048-1 specifies image formats 4K and 8K. These formats may also be used to create high-quality content for other applications of digital cinema. This standard defines the formats compatible with freely defined color space format *Free Scale-Gamut* (*FS-Gamut*) and a freely definable characteristic *Free Scale-Log* (*FS-Log*) of primary colors signals transmission. Chromaticity coordinates of the primaries and reference white D65 in the DCDM system on default are defined as equal $x_{R_{FS}} = 0.7347;\ y_{R_{FS}} = 0.2653;$

$$x_{G_{FS}} = 0.14;\ y_{G_{FS}} = 0.86; \qquad x_{B_{FS}} = 0,1; y_{B_{FS}} = -0,02985; \qquad x_W = 0.31272; y_W = 0.32903.$$

SMPTE ST.2065-2 specifies ACES system and appropriate digital color image encoding appropriate for both photographed and computer-generated images, based on use of additive color space of *R,G,B* primaries. Chromaticity coordinates of the primaries and reference white D65 in the DCDM system on default are defined as equal $x_{R_{FS}} = 0.7347;\ y_{R_{FS}} = 0.2653;\quad x_{G_{FS}} = 0.0;\ y_{G_{FS}} = 1.0;$

$$x_{B_{FS}} = 0,0001; y_{B_{FS}} = -0,077; \qquad x_W = 0.32168; y_W = 0.33767.$$

The ACES color space type can also be considered to be of the type input-device-dependent. The full range of valid color component values should not be clamped except as needed to produce a desired artistic intent. ACES is scaled such that a perfect reflecting diffuser under a particular illuminant produce ACES values of 1.0. Many scenes include objects with radiance values greater than that of a perfect reflecting diffuser hence ACES values well above 1.0 are expected. So it is possible in this system transmission scenes including self-luminous objects.

Thus, the trends of technical progress of infocommunication and other video applications are aimed to improving image definition, extending transmitted color gamut, extension bit depth of digital encoding, possible use of a logarithmic scale the transmission component signals and on this basis to achieve a new level of image contrast ratio, for example, implemented in high dynamic range imaging, as well as creating new opportunities to freely set transmitted color gamut and transmission characteristics of component signals.

V. ACTUAL IMAGE QUALITY IMAGES ON THE CHARACTERISTIC OF REAL EQUIPMENT

Actual image quality is limited by characteristics of equipment and of image processing on the transmitting and receiving sides. There are a number of factors limiting actual image quality in through end-to-end video path

Limitation of image definition with respect to the defined by system characteristics is determined, first of all, by the characteristics of the camera lens. In particular, limited depth of field of the leads to the fact that full definition is realized only in the focal plane of the lens and decreases with distance of the scene points from the focal plane. In connection with the development of stereoscopic television technology there is a new opportunity to correct blurred images of three-dimensional scene using the depth information of the image at each point and the management of compensation system.

Limitation of definition may also occur due to the distortion introduced *to* spatio-temporal MTF during processing in the video path including compression system. It is possible to limit definition reduction by entering normalization MTF of through light-to-light video path considering a compromise between the degree of approximation the definition to the potential definition and sampling distortion, as well as artifacts inherent in digital processing.

Color distortion is defined by constraints introduced by the studio light sources and by imperfection of the spectral characteristics of color separation systems of cameras, by possible deviations of display primaries chromaticity coordinates from specified system coordinates, which may depend on the content of the image, as well as possible errors introduced during digital processing. This kind of distortion can be limited by appropriate normalization characteristics of respective units of light-to light TV path.

Distortion introduced by the transmission path are defined by the coding system and the characteristics of the transmission path. They are determined by a compromise between compression extent and insertion distortions, as well as characteristics of the path.

Optimal subjective quality of color TV image corresponds to the resulting gamma factor of video path equal to 1.2 . It should also be kept in mind that the perception of image color and halftone is affected by image processing corresponding to image contouring, such that image details of the image appear higher in contrast with the proviso that contouring unnoticed or, at least, on the edge of visibility, but also color distortion should be normalized in relation to colors, reproducible at the output of appropriately configured video path. Degree of image contouring should also be considered when evaluating the image quality due to the compression of the image. Thus contouring at the transmitting and receiving sides may affect differently on display artifacts occurring in the path of a compressed image.

VI. INFLUENCE OF VIEWING CONDITIONS ON TRANSMITTING AND RECEIVING SIDES ON PERCEIVED IMAGE QUALITY

In the framework of the color coordinates *X*,*Y*,*Z* of CIE-31 system undistorted color reproduction corresponds to the equality of coordinates of the object (O) and image (I):

$$X_{\mathrm{I}} = X_{\mathrm{O}}; \quad Y_{\mathrm{I}} = Y_{\mathrm{O}}; \quad Z_{\mathrm{I}} = Y_{\mathrm{O}}. \tag{1}$$

At the level of modern concepts color is characterized by the indexes of lightness J', colorfulness M' and hue h' of uniform color space CAM02-USC [19] based on the color appearance model CIECAM02 [20]. Accordingly undistorted color perception can be represented as:

$$J'_{\text{И}}\big|_{\text{cond. 2}} = J'_{\text{O}}\big|_{\text{cond. 1}}; \quad M'_{\text{И}}\big|_{\text{cond. 2}} = M'_{\text{O}}\big|_{\text{cond. 1}}; \quad h'_{\text{И}}\big|_{\text{cond. 2}} = h'_{\text{O}}\big|_{\text{cond. 1}}, \tag{2}$$

where “cond. 1” and “cond. 2” are determined by adapting luminance $L_A = L_W/5$, L_W – luminance of white, and viewing conditions.

Possible difference between the image on viewing conditions at transmitting and receiving sides leads to difference of color coordinates of the object and the image, indicating the possibility of distorted color reproduction.

VI. PRINCIPLES OF BUILDING ADAPTIVE IMAGE QUALITY CONTROL SYSTEMS IN FUTURE VIDEO APPLICATIONS

On the base of Ukrainian propositions [1, 2] principles of adaptive image quality control are specified in Recommendations ITU-R BT.1691-1 [24] and ITU-R BT.1692-1 [25]. The idea of adaptive image quality control is following.

An objective of television broadcasting is to obtain optimum (for digital TV applications) subjective quality of the reproduced image for any programme content, any type of image compression, any source and reproducing devices, and any viewing conditions. The receiver of the future may implement adaptive processing that can calculate necessary processing parameters for optimum image quality. Nominal parameters for image processing at the transmitting and receiving ends may be generated at the transmitting end and transmitted for use by image processing devices at the receiving end.

In Recommendation ITU-R BT.1691 it is defined that future TV systems may operate at either of two levels: non-adaptive and adaptive digital TV systems. The recommendation specifies:

– that in adaptive digital TV systems methods of global optimization of image quality should be used, either by optimization of individual parameters, or by optimization of grouped parameters;

– that for image quality optimization, information is needed on the characteristics of the transmitted image, on viewing conditions, on transmission conditions, on the method of presentation, and on any intermediate devices in the signal path which may affect the signal quality. This information should be inserted in a defined location in the bit stream so that it may be read by adaptive signal processing devices at the transmitting and receiving ends;

– that adaptive digital TV systems should be compatible with existing digital TV systems.

In Recommendation ITU-R BT.1692 it is defined that in future there will be two system levels: non-colour-adaptive digital TV systems and colour-adaptive digital TV systems. The recommendation specifies

– that technical solutions for colour-adaptive digital TV systems should be based on use of colour appearance models built with consideration of the adaptation of the human visual system to viewing conditions (possibly different) at both ends of the light-to-light TV path;

– that colour appearance models may be a part of future systems, and in this case the system becomes a colour-adaptive digital TV system;

– that backward compatibility is necessary for colour-adaptive digital TV systems;

– that in future additional viewing conditions should be recommended for viewing colour television.

Implementation of adaptive video technologies may be new step of technical progress. This step, firstly proposed for TV application, may be implemented to any infocommunication video applications.

The image quality depends on many factors, among which are :

– factors characterizing technical level of the equipment used for capturing, processing and reproduction of video scenes;

– factors associated with the semantic content of the image, its detail, luminance and color halftones content;

– factors related to image viewing conditions in points of image capturing, processing during production and post-production, as well as reproduction.

All this set of factors suggests that a full assessment of image quality is a vector and a variable over time, as well as varying depending on the capturing conditions, which differ from scene to scene, and for different users, conditions of perception of which are different.

So there may be different levels of image quality assessment and quality control, characterized by degrees of completeness and with varying degrees of reliability describing the quality of video applications. These levels may be implemented depending on the application and accordingly demands placed on them.

In terms of subjective evaluation carried out in the laboratory, it is desirable to filter the transmitted scene in such a manner as to take into account the maximum number of factors that appears simultaneously. This approach may allow to minimize dimensionality of assessments vector.

Subjective evaluation can be implemented with a certain degree of reliability as an objective quality assessment carried out by qualimeter algorithm of which takes into account the characteristics of observer visual system and quality evaluation criteria.

Further progress of image quality evaluation and monitoring methods for in existing infocommunication video applications must be directed to regulatory and metrology provision oriented for optimal assessment implementation, taking into account , on the one hand, the opportunities and the availability of this implementation, on the other hand, the desire for its possible perfection.

To problem matters of assessment and monitoring of distortions in light-to-light video path of infocommunication video applications is the need to adapt existing methods of video path performance evaluation most fully developed for standard definition television systems to systems at different levels and the corresponding development of metrological provision.

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