Ministry of Education and Science of Ukraine
O.S. Popov Odesa National Academy of Telecommunications

V.V. Pyliavskyi, O.V. Gofaizen,
O.V. Osharovska, M.O. Patlayenko,
V.I. Solodka, D.A. Makoveenko, S.V. Siden

TRENDS IN TELECOMMUNICATIONS AND MULTIMEDIA SYSTEMS

Monograph

Kyiv
Publishing Lira-K
2020

UDC 621.397
P32

Recommendation to print
Academic Council of ONAT n.a. O.S. Popov
(Protocol № 1 of 26 August 2020)

Reviewer:
Douglas Lee Hall, Ph.D., Chair (Retired), Computer Science Dept., St. Mary's University, San Antonio, Texas

Pyliavskyi V.V., Gofaizen O.V., Osharovska O.V. and other
Trends in Telecommunications and Multimedia Systems : monograph. Kyiv: Publishing Lira-K, 2020. 248 p.

ISBN 978-617-7910-68-7

The monograph provides comprehensive information on modern trends in telecommunication and multimedia information transmission systems. The modern aspects of the development of individual elements of the complete data transmission path are presented. The monograph consists of 9 chapters, in which modern issues of light-to-signal conversion are considered in detail, taking into account external light sources, encoding and compression of multimedia information, as well as features of reproducing devices. In addition, the main characteristics of the radio interface of the 5th generation of mobile communications, as well as its main technologies, are considered.

The results presented in this monograph can be useful for scientists, engineers interested in the current state of telecommunication systems for transmitting multimedia information, as well as for graduate students and students of higher educational institutions in the field of telecommunications and radio engineering.

ISBN 978-617-7910-68-7

CONTENT

REVIEW

The book is aimed at expanding the understanding of traditional light-to-light pass-through paths which do not currently take into account the effect on color rendering of the properties of the final equipment and lighting sources. It expands the area of knowledge related to color rendering by multimedia systems, their features, their current state, and promising ways of development.

The text presents general issues of colorimetry, namely, the question of spectral characteristics of the sensitivity of vision, the sensitivity of the color channels of the camera, and algorithms for describing the properties of color perception.

Material concerning the Planck curve and isothermal lines from the point of view of perception is presented. The expediency and effect of using the presented analytical expressions is shown in the following sections.

It should be noted that the issues of metrological support of modern multimedia systems are considered. It is proposed using a set of test colors – color atlases, which are built using the properties of color perception – to replace the traditionally used colors used in test tables. So, these metrological tools for measuring the quality of color transfer are more effective and appropriate when used to replace existing ones. This is primarily because they have a large sample of test colors which undoubtedly increases the measurement accuracy. Expanding the set of test colors will allow you to evaluate not only saturated colors, but all colors that can be transmitted by the system.

Attention is focused on the pressing issues of color rendition quality, pointing out that even if the entire track is adjusted so that no distortions are introduced in the transmitted information, there are still points where the distortions have unacceptable values. That is why in the last chapters the authors propose for consideration an algorithm that can be used to correct the transmitted signal.

The authors note that the spectral characteristics of the light source should be attributed to possible distortions, as a factor that has a significant impact, the magnitude and nature of which is presented in the monograph. Along with this, it is noted that even if the color is not transmitted distorted, then the conditions in which the observation takes place – dark, dull, bright – also affect the quality of color perception This means this factor should be taken into account. Other factors include the properties of the final equipment, as well as the primary signal processing.

The proposal presented in the chapter on the creation of an algorithm for adaptive correction of the transmitted image signal is urgent and extremely important for special applications.

It is desirable to continue research and expand understanding of the calculated need for the implementation of this algorithm and the design differences of the end equipment of telecommunication paths.

The text contains data describing the optical apparatus, as well as methods for evaluating end devices based on test images with a gradient frequency change in the direction of the horizontal and vertical images. It should be noted that special attention is paid to the construction of test signals, analytical formulas are presented that describe the shape of the test signal, taking into account the parameters of the end-to-end path.

The book deals with compression systems, representation of images in different bases and their processing methods. The research presented in the book aims to improve existing compression techniques. It should also be noted that the proposals presented in the book can be used to build promising new compression systems.

In the section on the representation of images in a spectral form, methods of boundary detection are actively used, which are used by telemedicine applications as well as special applications.

In the chapter "Complex algorithm of image wavelet compression – a possible way of progressions digital image processing", the reader is presented with a feature that is not taken into account in existing compression algorithms. This is the study of the high-frequency component in the image, the dependence is shown, with which it is possible to determine how much the amount of transmitted data on the high-frequency components in the image can be reduced with constant quality.

Further, the reader is offered an analysis of compression systems based on wavelet compression, detailed information on the technical parameters, and algorithmic features of the proposed changes are presented. The main improvements include tracking motion vectors and the similarity of areas of transmitted images.

The results of research concerning volumetric television are also presented, as well as the transmission of information about volumetric images by communication channels. The research was carried out using interpolation methods according to various laws. Recommendations are given which should be applied for the possibility of transmitting the frequency components of scene objects.

In the text, the results of the analysis of the fifth generation communication system are presented, as well as the main analytical expressions for calculating energy indicators in the network coverage area. The authors have made proposals for the use of antenna systems that can be used in fifth generation communication systems and in subsequent generations of communication. Attention is focused on the application of the algorithm for energy-oriented communication with subscribers in the network coverage area.

The textbook presents up-to-date data based on international progress in this area. The materials of the textbook will be useful for specialists in a wide sector and developers of new end-to-end video transmission paths. Another area of application is artificial intelligence, where the parameters of the communication channel are decisive in pattern recognition.

Douglas Lee Hall, Ph.D.
Chair (Retired), Computer Science Dept.
St. Mary's University
San Antonio, Texas

INTRODUCTION

The rapid development of technology takes on such a rhythm when a modern person no longer has time to learn about the progress made in various fields of science. On the other hand, the service provided by progress is an integral part of the modern person, and further progress is more desirable than regression or stagnation.

Cellular communication systems, wireless Internet, video calls, instant messengers, video filming using portable gadgets, photo and video processing systems, video viewing services next to traditional terrestrial television systems, as well as cable television and satellite services that provide information via broadcast or at the user's request are examples of a few special cases of essential services of modern human life.

This book will consider the issues of the current state and promising ways of developing progress as an integral part of the life of every person – telecommunication and multimedia systems.

It should be noted that the text is aimed at a reader who has elementary ideas about the formation and transmission of information by telecommunication and multimedia paths.

As an illustrative example, the book selects an end-to-end path for transmitting visual information along a telecommunications path from the shooting point to the playback point on the viewer's side. The structure of the end-to-end path is shown in the figure.

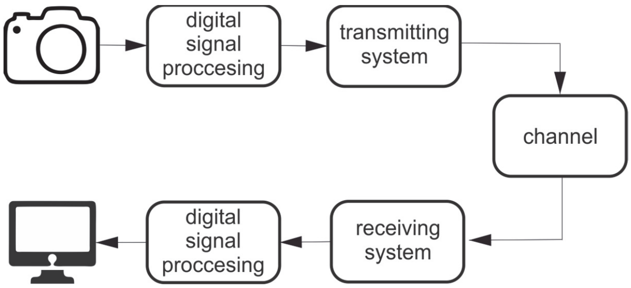

Figure 1 – A simplified scheme of the through video path

It should be noted that the results of this book are a continuation of the work of scientists who have already made a significant contribution to the development of the presented through path. These include V.K. Zvorykin, M.I.Krivosheev, D. Wood, J. Nishida, K. Dorsch – all of whose works reflect the modern progress of video technology.

Millions of elements in high definition and ultra-high definition are widely used in photography, multimedia applications and filmmaking. The quality of such images is ensured by digital processing methods at all stages of creation, transmission, storage, and reproduction. These images, projected onto large imaging devices, show fine details such as surface texture. There are several critical parameters for a subjective assessment of image quality – color rendering, contrast, sharpness, clarity. During processing and storage of such images, information is compressed, which leads to a change in subjective quality. False contours appear in images, colors change, moire appears, and texture disappears. The development of image compression methods that do not lead to a significant deterioration in quality, but reduce the required amount of memory, is one of the urgent tasks.

Image definition is one of the critical indicators that determine the subjective quality of reproduction. Objectively, the number of picture elements that potentially can be reproduced in a television system defines definition. A feature of human vision is the fact that the perceived definition is influenced greatly by the contrast of the image the contrast of small details. To assess the potential definition, the book analyzes the space-frequency-contrast characteristic (MTF) of the path "from light to light" and the effect on it of all processing links, from the lens to the display. Test signals are also available to measure spatial frequency contrast in two dimensions.

The goal of modern surround television systems is striving to reproduce the optimal quality of a 3D video sequence, which corresponds to the maximum implementation of the system within the available resource, which is the problem of efficient storage and fast synthesis of 3D images.

The realization of this goal in the modern world of television uses a representation of a 3D object in the form of a mesh consisting of the coordinates of the vertices of this object and the order of their connection. An increase in the detail of 3D images is provided by a decrease in the mesh step in complex areas, which, in the general case, indicates a fundamentally uneven sampling in 3D space.

The book consists of nine chapter, each chapter is devoted to a separate part of the end-to-end path. The order of the chapters corresponds to the sequence of the constituent links of the path shown in the figure.

Chapter 1 “Color rendering in end points of telecommunications and multimedia paths” presents material that goes beyond the traditional understanding of the end-to-end path presented in the figure. The difference lies in the fact that in the traditional end-to-end video transmission path, the first point is the light-to-signal converter; in the presented book material, it is proposed to consider the human eye as the first point of the through path.

Considering that on the way from the scene object to the “light-to-signal” conversion device on the transmitting side and the “signal-to-light” conversion device to the observer there is a light source that can be natural or artificial and the application at a certain point in time of one of them predict impossible this leads to a difference in the perception of the color of the object. If we assume that the subsequent nodes of the path do not introduce distortions or they are negligible, then in the specified area color distortions take place, more detailed studies are presented in the section.

Considering that in the world there is no international standard for the characteristics of cameras and displays for undistorted color reproduction, and even if there were, most manufacturers do not adhere to them, as evidenced by a wide variety of types of signal-to-light and signal-to-light converters from one manufacturer. Consequently, the difference in characteristics, primarily spectral in the range of frequencies visible to human vision, leads to a violation of color reproduction.

These and other features require an algorithm that is designed to ensure consistent color reproduction. Thus, the book proposes an algorithm that can be used to achieve this goal.

Chapter 2 "A complex algorithm of image wavelet compression – a possible way of progressions digital image processing" provides a quantitative assessment of the achievable image definition calculated using the transfer function of the two-dimensional spatial frequency-contrast characteristic (MTF) of the television system. The limitations inherent in the camera lens, the distortion introduced by the camera sensor and the screen display, arising from the finite dimensions of the conversion element, and the effective size of which is equal to the image element of the scanning system are taken into account. Questions are discussed and an algorithm is proposed for possible correction of arising distortions for a wide range of camera parameters and sensor sizes. The MTF of a camera lens depends on its design and settings and can depend on several types of distortions inherent in different lens implementations. The development of optics has led, in the ideal case, to various types of distortions that can be compensated by the lens design, and the fundamentally achievable image definition provided by the lens is limited by the diffraction limit and depends on the light wavelength, the lens aperture angle, and the final vertical size of the matrix sensor.

In the practice of analog television, for a long time, the MTF has been used to assess distortion along the scan lines resulting from minimal distortion in the electrical signal transmission path. As one of the criteria for such an assessment, the area under the MTF of a television system "from light to light" was sometimes used within the standard video signal bandwidth, which characterizes the average horizontal level of the MTF.

In the case of evaluating distortions using a two-dimensional MTF, an appropriate measure for determining image quality can be the volume of space under the two-dimensional MTF for the frequency range within the cube, limited by the spatial Nyquist frequencies for the horizontal and vertical directions.

Chapter 3 "Potentially achievable image quality in video applications" provides a quantitative assessment of the achievable image definition, estimated by the two-dimensional spatial modulation transfer function (MTF) of the TV system.

Chapter 4 "Image spectra with different transformation kernels" is devoted to the assessment of the achievable compression ratio and the corresponding distortion of the image boundaries depending on the parameters of spectral transformations with quantization of coefficients. The JPEG and MPEG compression algorithms use Discrete Cosine Transform (DCT) with a wide variety of coefficient quantization matrices. However, to date, requirements for assessing the quality of reproduction after decoding fine-structured changes in textures of digital images have not been developed. The influence of the main parameters of threshold functions on the formation of boundaries and textures of reconstructed images is determined. Optimality is determined by the maximum signal-to-noise ratio at the edges of the image.

For signals of large dimension, Riesz transforms and partial Hilbert transforms are considered for calculating the local phase and local orientation of video scene objects.

Spectral transforms, using more complex bases than Fourier transforms, allow the extraction of more image features at different spatial frequencies.

Gabor filters with different frequencies and orientations in different directions are used to localize and isolate only certain areas from complex images. Gabor filters are also widely used in face recognition applications. Two-dimensional Gabor filters are widely used in object extraction for analysis and texture segmentation. Different textures have different spatial frequencies by which they can be classified.

In this chapter, the amplitude-frequency and phase-frequency characteristics of the test image obtained for different spatial frequencies at the output of the Gabor filter are investigated. The image was processed with the Gabor filter, in which the spatial frequency was changed from the maximum frequency to a lower frequency corresponding to eight pixels.

Chapter 5 "Test signals for assessment image quality in HD and UHD TV video path" addresses the development of still images compression methods and intra-frame compression of video sequences that are key elements in the creation of systems for broadband transmission of images for various purposes. In this case, the main criterion for the range of the compression ratio is the estimates obtained by measuring the distortion of the sharp edges of the image arising from the wavelet processing implemented in the compression process. This chapter focuses on the choice of the threshold level based on the trade-off between the achievable compression ratio and the possible preservation of the image texture and presents the corresponding estimates.

The study of the complex wavelet processing characteristics was carried out on the basis of wavelet decomposition based on the use of FIR filters, prediction of high-frequency coefficients from low-frequency ones. To estimate the possible compression ratio, if the fine texture is preserved, estimates of the distortion of the reconstructed image and the compression ratio are obtained for two variants of frequency-dependent quantization of the video signal with 10-bit coding. The resulting assessment showed that the use of a complex still image compression algorithm achieve a compression ratio of up to 100 under the condition that the restored image is of high quality. It combines the limitation on the minimum absolute values of the sub – bands of the image decomposition levels (except for low frequency ones), frequency-dependent image decomposition levels, prediction of the signal of the quantization sub – band and prediction bit planes.

In Chapter 6 "Video information compression algorithm at fixed image quality" an algorithm for compressing video information with a fixed image quality is considered. As part of the study, the analysis of the dependence of the quality of the video codec based on wavelet transforms and the amount of data lost during transmission over the communication channel was carried out, and recommendations for the use of the video codec based on wavelet transforms in streaming video were developed. In addition, studies were carried out to assess the quality of a video codec based on wavelet transform using the proposed EQM metric (Error Quadratic Means) and to estimate the compression ratio of the original video sequence of a video codec based on wavelet transform.

The problem of detecting and analyzing the quality of the video codec was solved based on wavelet transformations in terms of packet loss in the communication channel. Based on the quality analysis, several recommendations were developed for using the video codec in streaming video. It is proposed to highlight the highest priority packages containing low-frequency coefficients. Analysis of loss scenarios shows that when more than two levels of coefficients are lost, the quality of the video stream becomes difficult for subjective perception. Therefore, it is recommended to distribute the main packages as follows: transmission of three levels of coefficients is guaranteed. Four-level transmission improves the quality of the received video sequence. However, a 50% increase in the size of the transferred file is required.

The study assessed the effect of the type of wavelet transform on the quality of the encoded video stream in terms of partial data loss. Comparison of six types of wavelet transforms showed that the video codec based on the Daubechies wavelet transform showed the best results.

Chapter 7 "2D and 3D video objects wavelet compression" analyzes the estimates of the coordinates of three-dimensional television objects obtained in three-dimensional models of real objects. At present, interest in the problems of constructing polygonal-mesh 3D images has significantly increased. This manifests itself, in particular, in the processing of two-dimensional and three-dimensional television objects. In this case, it is necessary to evaluate the most important characteristics, such as the signal-to-noise ratio and the measurement error of coordinates. To build complex volumetric objects, a grid with a non-equidistant step is used, which allows objects with higher accuracy to be detailed. Accordingly, for high frequencies, i.e. for complex parts of the object, it is necessary to describe many triangles, and at the same time a smaller sampling step is chosen.

For low frequencies, i.e. for less complex areas of the object, the sampling step is increased, and the number of triangles decreases.

Much attention must be paid to the level of quantization, which shows the bit depth of the vector. Z-coordinate is the least critical coordinate to the rotation angle, because it determines the depth of the object. It is known that the resolution of the human visual system is the least sensitive to depth, so the Z axis can be subjected to a larger quantization and sampling step. The study of hierarchical spectral transformations for the selected thresholds made it possible to improve the quality of mesh objects reconstruction.

Chapter 8 "Overview of the 5G radio interface technology" provides an overview of the radio interface of 5th generation mobile networks (5G). The main technical characteristics, services, and use cases are described. The main technologies are presented that allow the required quality characteristics of 5G networks to be achieved. The basic calculation formulas for planning the coverage of 5th generation networks for various use cases are given: Indoor Hotspot, Dense Urban, Urban macro, Urban micro, and Rural environments. In addition, a generalized propagation model is presented, which considers losses for penetration through elements of buildings and structures, losses in rain, and atmospheric gases.

Chapter 9 "Use of adaptive antenna arrays to reduce interference in the E-UTRA network" presents the results of analyzing the network throughput when using adaptive antennas using the example of the 4G LTE (E-UTRA) network. To assess the benefit from the use of adaptive antenna arrays, two options were analyzed: using a standard antenna array of the LTE-A network, and an adaptive linear equidistant antenna array. The distribution of throughput (transport block size) for 50 resource blocks is presented when using an adaptive equidistant linear antenna array in comparison with a standard antenna array.

1. COLOR RENDERING IN END POINTS OF TELECOMMUNICATIONS AND MULTIMEDIA PATHS

1.1 Use of a color appearance model for video applications

The task that any video application, including TV systems, decides is the transfer of the law of color distribution in the space of the transmitted scene and its reproduction so that from the point of view of the observer the function of color distribution in the reproduced image corresponds to the maximum degree of the function of color distribution in the transmitted scene. Thus, the basis for building and improving TV and other video systems is largely an implementation of the principles of colorimetry, video technology, and digital image processing. The most difficult task is the color perception model. The level of implementation of new video applications and the possibility of their further progress depend on the degree of perfection of this model.

In this paper, we consider the current level of color perception models and their use in video technologies. An assessment of existing problems is given, a number of tasks are set, and ways of their solving the ways of their solution are outlined.

1.1.1 Requirements for color perception models

To date, the most perfect model among the standardized color models in the world is the CIECAM02 [1.1]. This model embodies the mechanisms for transforming the sensations of color in the human visual system at the level of modeling the characteristics of the cone apparatus of vision. It takes into account the adaptive properties of vision represented by models of color and brightness adaptation to the lighting characteristics of the scene in question. The adapting factors are the absolute coordinates X_W, Y_W, Z_W, reference white, and adaptive L_A, which, with the brightness of the reference white L_W corresponds to the brightness of the surrounding background L_b and is $L_A = Y_b L_W = \frac{L_b}{L_W} L_W$, coordinate Y of the adaptive background. For detail see Fig. 1.1.

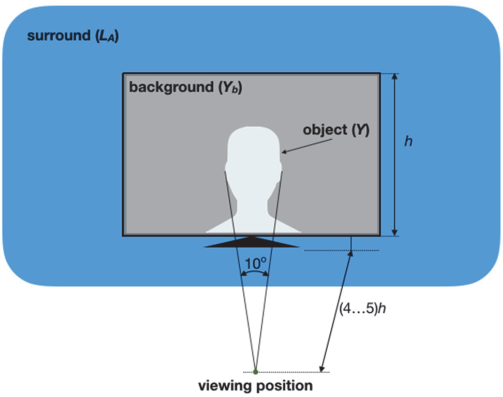

Figure 1.1. The adaptation parameters applied in television and multimedia adaptive systems

In this case, the area of the background color is limited to an area equal to 10 angular degrees. That is, from the point of view of the viewer of the video system, the objects of the perceived scene have a size of 10 [1.1].

From the point of view of possible scenes on the transmitting and receiving sides there can be various situations.

The camera transmits the scene of the open space and the viewer at the observation point adapts to the coloring of the object, its brightness, and to the whole observable space. This means that it is possible that is a parameter not only of the background of the scene but also of the entire observable space. In the book of Fairchild [*1.33*] it is indicated that taking into account the near environment is 60% coverage in the nearest active field of perception, and the remaining 40% is the color and brightness of space. The latter adapting circumstances is not taken into account by existing models of adaptation, so it requires further research

A more accurate account of the adaptive properties in the context of adaptation to the image under consideration is presented in the iCAM06 model [1.2].

1.1.2 Curriculum current status

For the construction of an adaptive video transmission system involves the use of a color perception model, namely, CIECAM02 [1.1]. In [1.3], a possible model of an adaptive video communication system is proposed.

But the standard [1.1] used in constructing an adaptive model does not indicate the false operation of the system, but only indicates that the system may have negative coordinate values. The test on which the reliability of the system is based on one point and to determine the true work of the whole color chart is not possible. An error may be indicated but it is not taken into account. Therefore, there is a part of the diagram that is reproduced correctly, and there is a part where the reproduction is incorrect. The boundary between these areas is still unknown.

Measuring the correctness of the region of the transmitted colors was carried out using a radial grid by uniform distribution of points of color in radii, with a step of 1 unit of CIE. Although the person perceives the difference in 4-6 units of CIE, but for a detailed study of the correct use of the model was the minimum grid step. The number of radii equal to $360^{0}/20$ this ratio satisfies the compromise between accuracy and size of data for further operation of the data.

On Fig. 1.2 and 1.3 there are the following symbols: a_M, b_M – the color axis, green-purple and blue-yellow, respectively, (·) – are the points of color of the radial grid, which uniformly fill the region of color and transmitted by the system of ultra-high definition, (x) – color points a radial grid that evenly fills the color area and is not transmitted by the ultra-high definition television system, (**o**) – the points of the color of the radial grid, which uniformly fill the region of color but are incorrectly reproduced in the coordinates of the system.

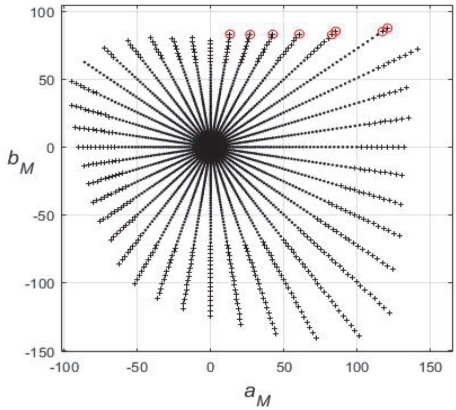

Figure 1.2. The evaluation of the correct use of the forward conversion of the color perception model CIECAM02

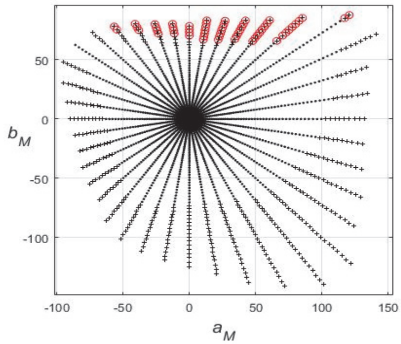

Figure 1.3. The evaluation of the correct use of the invers conversion of the color perception model CIECAM02

1.1.3 The cone and the mesopic vision

The adaptive color rendering model has a working brightness range and most often they are divided into scotopic and mesopic. If the scotopic area is devoted to many works and methods of application are obtained in their data [1.4-1.5].

But the transmission of video information can be carried out either in a bright spot or in sunny bright light and in sunset twilight. Therefore, a necessary condition for building a full-fledged adaptive video transmission system is the recording of both the scotopic and mesopic regions.

The assessment of the area of transmitted colors by broadcast systems, based on which video transmission systems are currently being built, is shown in Fig. 4. Where there are triangles of chromaticity and also the coordinates of the main and additional colors. In Table 1 data are presented that indicate the percentage of transmitted and reproduced colors in different brightness to the maximum distance transmitted in the mesopic region The maximum brightness of the mesopic region is taken to be equal to the relative brightness of the image equal to 0.5 for UHDTV (ultra-high definition television).

1.1.4 Accounting geometric dimensions of color details

Taking into account the geometric dimensions of objects under conditions of adaptive information transfer and playback on the screen can significantly change the adaptive properties of the visual apparatus of the observer. Two values of 2 and 10^o are standardized (see Fig. 1.4) but the latter is used in television.

More details about quantitative assessments of the influence of the angular parameters of color transfer can be found [1.6].

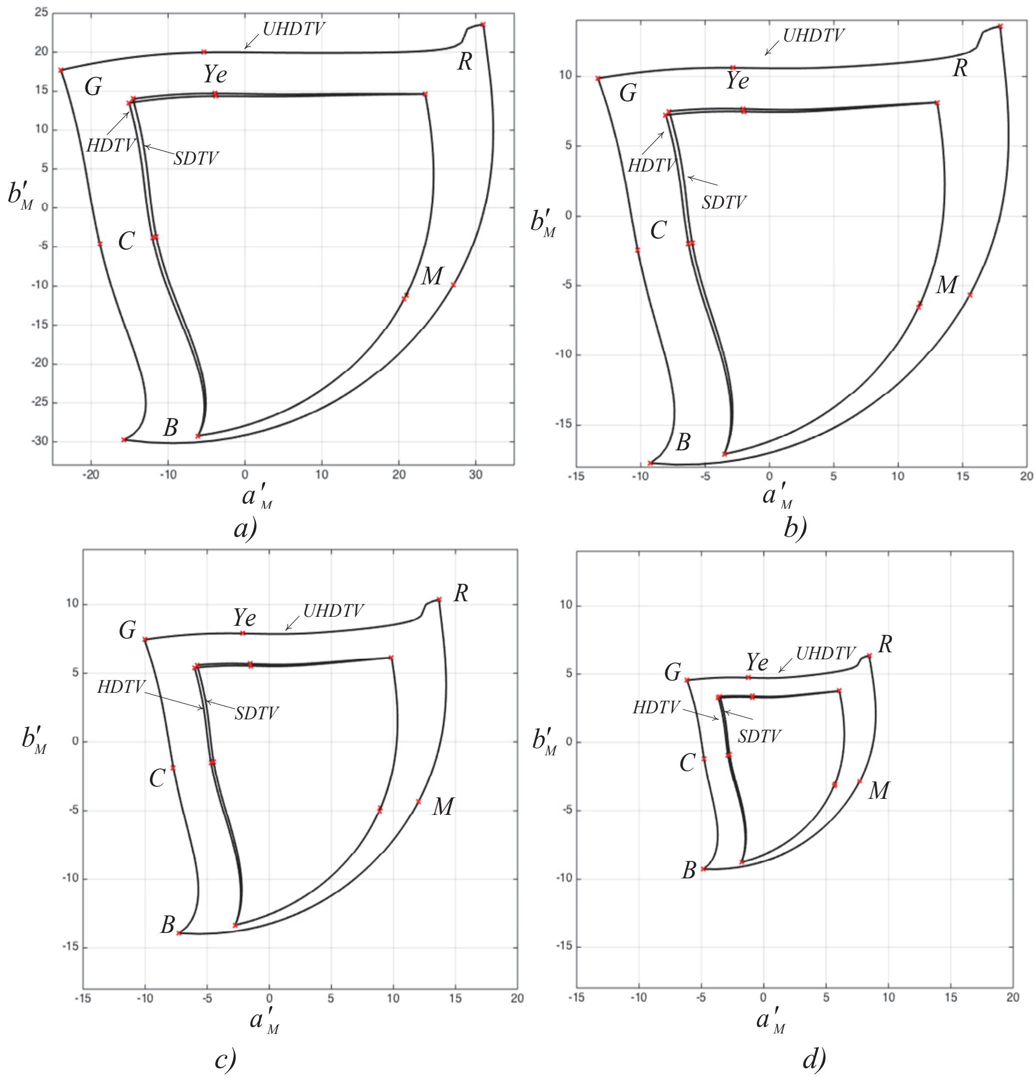

Figure 1.4. Area of color mesopic vision of CAM02-UCS coordinate transmitted and reproduced by SDTV, HDTV and UHDTV systems for luminance (*Y*): a) 0.5; b) 0.05; c) 0.02; d) 0.005

Assessment area of color of mesopic vision are presented in Table 1.1.

Table 1.1. **Area of Color Perceptual Mesopic Vision which Transmitted and Reproduction TV systems**

Y	SDTV		HDTV		UHDTV	
	AT*	%	AT*	%	AT*	%
0,005	87	0.040	88	0.040	161	0.074
0,020	221	0.107	223	0.102	405	0.186
0,050	383	0.176	386	0.177	692	0.320
0,500	1264	0.580	1274	0.585	2178	1.000
AT* – area of triangle transmitted or reproduction by television or other multimedia systems						

Use the color perception model CIECAM02 in the form in which it is presented in the international standard in video communication systems is not possible. To use it when adapting video, analytical actions should be performed, which are presented in [1.3, 1.7].

It should also be noted that the system was designed to work with still images, so in the future it is necessary to investigate the use of the model for processing video sequences in real time.

1.1.5 Objectives of adaptive video systems its prospects and problems

From the point of view of the implementation of new adaptive systems for the transmission of video by communication channels that will take into account the adaptive properties of vision, we are talking about adaptation to brightness, chromaticity. It should be used color perception models that work correctly in the entire range of brightness and transmit the correct color information.

Proceeding from this, it can be assumed that the new systems of adaptive transmission of video information will not only have the adaptive properties of the object and its background, see Fig. 1.1, but also the background of the reproducing device.

Also, new systems should be priced taking into account the wide range of transmitted brightness, starting from the mesopic vision, scotopic, and ending with high brightness values.

It is not an unimportant necessity to adapt to the spectral distribution of the surrounding background. The latter should be attributed as different types of lighting sources, see Fig. 1.5., where conventional standardized lighting sources (x) and fluorescent types (x) are presented in the coordinates of the equally contrasted CIECAM02 system.

Simultaneously with these sources of illumination, there are many others, for example, illumination from car headlights, moonlight, sunset, dawn, signal rocket, etc. That excludes the possibility of accounting for all types of lighting sources, so the area of existing models of color perception needs to be expanded in relation to the specified adaptation condition This seems to be one of the further tasks of progress in this field, as some information presents 1.8].