

# UTILIZATION OF MATLAB FOR TV COLORIMETRY AND COLOR SPACES ANALYSIS

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## Abstract

The contribution deals with the Matlab application used for television colorimetry and color spaces analysis. The mathematical description of known color spaces (RGB, XYZ, YUV, YIQ, YCbCr, HSV, CMY, CMYK) is introduced including their reciprocal transformation. The application allows selection of input color image, direct and backward transformation into the selected space including MKO, CIE and RG diagram picture analysis. The projection of color image in 2D and 3D color vectors is then possible. The additional functions are evaluation of histogram, gamma correction, picture line selection for the analysis etc. The Color\_Spaces application outputs are introduced in examples applied on various test pictures.

## 1 Introduction

A monochrome or grayscale video image may be represented using just one number per spatio-temporal sample. This number indicates the brightness or luminance of each sample position. The larger number indicates a brighter sample. Representing color requires multiple numbers per sample. There are several alternative systems for representing color, each of which is known as a color space. The color space is a mathematical representation of a set of colors. There are several kinds of common color spaces for digital image and video representation. The three most popular color models are *RGB* (used in computer graphics eg.), *YUV*, *YIQ*, *YCbCr* (used in video systems eg.) and *CMY* and *CMYK* (used in color printing eg.). However none of these color spaces are directly related to the intuitive notions of hue, saturation and brightness. This resulted in the temporary pursuit of other models such as *HSV*, to simplify programming, processing and end-user manipulation [1] [2].

## 2 Color reproduction

Human vision is sensitive to the spectral content of light, giving the property we know as color. Although an exact physical reproduction of colored light would require a wavelength-for-wavelength matching of the spectrum of the light that is not necessary to produce a reproduction to satisfy a human observer. Only three attributes need be matched and there are many systems of three parameters that can be used. This examines light spectra and systems of matching color [3].

International Commission on Illumination CIE (Commission Internationale de l'Eclairage) defined standards for color matching functions and a diagram of chromaticity (see Figure 1) [2]. A set of imaginary nonphysical primary colors XYZ were chosen because they could match all the colors in the spectrum without using negative values. Primaries X and Z were chosen to have no luminance, meaning that value Y of primary Y carries all the luminance of color being matched. The other two values X and Z thus represent only the chromaticity of the color. Normalized values x and y of X and Y, called chromaticity coordinates, can create chromaticity diagram. Possible coordinates of diagram are x, y (MKO diagram), u, v (CIE diagram), r, g (color saturation diagram) [4] [5].

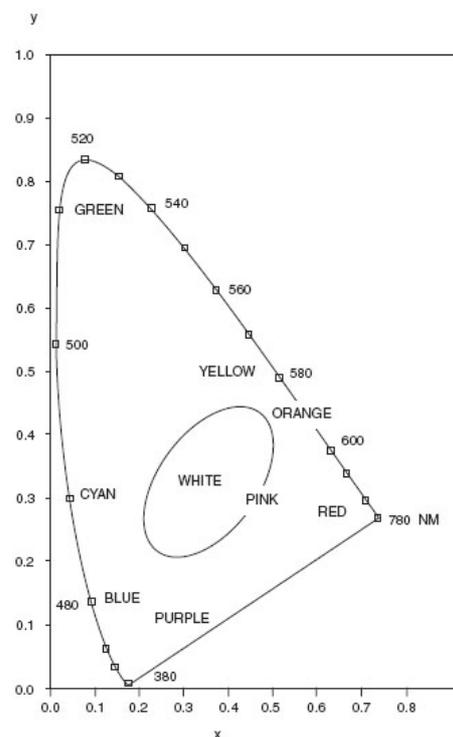


Figure 1: MKO chromaticity diagram.

Any three independent parameters can be used to specify colors. One system that is convenient because it relates to easily observed properties is *hue-saturation-brightness (HSB)* system [3]. *Hue* refers to the dominant color or wavelength and in chromaticity diagram it is quantified by passing a line from white to the color point out to the spectral curve. *Saturation* is the intensity or depth of the color. In the diagram it is indicated by how far the color point is from white towards to spectral line. *Brightness* is the same as luminance parameter. It is subjective evaluation of the total energy in the color and it is not shown in chromaticity diagram.



a) *RGB* picture



b) *YUV* picture



c) *YIQ* picture



d) *YCbCr* picture



e) *HSV* picture



f) *XYZ* picture



g) *CMY* picture



h) *CMYK* picture

Figure 2: Illustration of picture *Parliament* displayed in different color spaces.

All of the color spaces can be derived from the RGB information supplied by devices such as cameras and scanners. There is a list of common color spaces (see Figure 2). Details about different color spaces and mathematical background and description are available in [6] [7]:

- *RGB* color space - The red (*R*), green (*G*), and blue (*B*) color space is widely used throughout computer graphics. Red, green, and blue are three primary additive colors (individual components are added together to form a desired color) and are represented by a three-dimensional, Cartesian coordinate system. The indicated diagonal of the cube, with equal amounts of each primary component, represents various gray levels.
- *HSV* color space – The *HSV* (hue, saturation, value) color spaces was developed to be more “intuitive” in manipulating color and were designed to approximate the way humans perceive and interpret color. They were developed when colors had to be specified manually, and are rarely used now that users can select colors visually or specify Pantone colors. Transformation functions are built in Matlab and depend on immediate *RGB* components.
- *YUV* color space – The *YUV* color space is used by the PAL (Phase Alternation Line), NTSC (National Television System Committee), and SECAM (Sequentiel Couleur Avec Mémoire or Sequential Color with Memory) composite color video standards. The black-and-white system used only luma (*Y*) information; color information (*U* and *V*) was added in such a way that a black-and-white receiver would still display a normal black-and-white picture. Color receivers decoded the additional color information to display a color picture.

$$\begin{bmatrix} Y \\ U \\ V \end{bmatrix} = \begin{bmatrix} 0,299 & 0,587 & 0,114 \\ -0,147 & -0,289 & 0,436 \\ 0,615 & -0,515 & -0,100 \end{bmatrix} \cdot \begin{bmatrix} R \\ G \\ B \end{bmatrix} \quad (1)$$

$$\begin{bmatrix} R' \\ G' \\ B' \end{bmatrix} = \begin{bmatrix} 1 & 0 & 1,140 \\ 1 & -0,395 & -0,581 \\ 1 & 2,032 & 0 \end{bmatrix} \cdot \begin{bmatrix} Y \\ U \\ V \end{bmatrix} \quad (2)$$

- *YIQ* color space – The *YIQ* color space is derived from the *YUV* color space and is optionally used by the NTSC composite color video standard. (The “*P*” stands for “in-phase” and the “*Q*” for “quadrature,” which is the modulation method used to transmit the color information.)

$$\begin{bmatrix} Y \\ I \\ Q \end{bmatrix} = \begin{bmatrix} 0,299 & 0,587 & 0,114 \\ 0,596 & -0,275 & -0,321 \\ 0,212 & -0,523 & -0,311 \end{bmatrix} \cdot \begin{bmatrix} R \\ G \\ B \end{bmatrix} \quad (3)$$

$$\begin{bmatrix} R' \\ G' \\ B' \end{bmatrix} = \begin{bmatrix} 1 & 0,956 & 0,621 \\ 1 & -0,272 & -0,647 \\ 1 & -1,107 & 1,704 \end{bmatrix} \cdot \begin{bmatrix} Y \\ I \\ Q \end{bmatrix} \quad (4)$$

- *YCbCr* color space – The *YCbCr* color space was developed as part of ITU-R BT.601 during the development of a world-wide digital component video standard. *YCbCr* is a scaled and offset version of the *YUV* color space. *Y* is defined to have a nominal 8-bit range of 16–235, *Cb* and *Cr* are defined to have a nominal range of 16–240. There are several *YCbCr* sampling formats, such as 4:4:4, 4:2:2, 4:1:1, and 4:2:0.

$$\begin{bmatrix} Y \\ Cb + 128 \\ Cr + 128 \end{bmatrix} = \begin{bmatrix} 0,299 & 0,587 & 0,114 \\ -0,172 & -0,339 & 0,511 \\ 0,511 & -0,428 & -0,083 \end{bmatrix} \cdot \begin{bmatrix} R \\ G \\ B \end{bmatrix} \quad (5)$$

$$\begin{bmatrix} R' \\ G' \\ B' \end{bmatrix} = \begin{bmatrix} 1 & 0 & -0,698 \\ 1 & -0,336 & -0,698 \\ 1 & 1,732 & 0 \end{bmatrix} \cdot \begin{bmatrix} Y \\ Cb - 128 \\ Cr - 128 \end{bmatrix} \quad (6)$$

- *XYZ* color space – The *XYZ* color space was set by *CIE* (Commission on Illumination) and it represents set of imaginary nonphysical primary colors that were chosen because they could match all the colors in the spectrum without using negative values.

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix} = \begin{bmatrix} 2,769 & 1,741 & 1,130 \\ 1 & 4,591 & 0,060 \\ 0 & 0,057 & 5,594 \end{bmatrix} \cdot \begin{bmatrix} R \\ G \\ B \end{bmatrix} \quad (7)$$

$$\begin{bmatrix} R' \\ G' \\ B' \end{bmatrix} = \begin{bmatrix} 2,365 & -0,896 & -0,468 \\ -0,515 & 1,425 & 0,005 \\ -0,014 & 0,010 & 1,009 \end{bmatrix} \cdot \begin{bmatrix} X \\ Y \\ Z \end{bmatrix} \quad (8)$$

- *CMY* color space – The *CMY* (cyan, magenta, yellow) color space is derived from *RGB* and can be used for color image printing but because of ink imperfections, this system cannot reproduce black correctly. Therefore *CMYK* system is used instead.

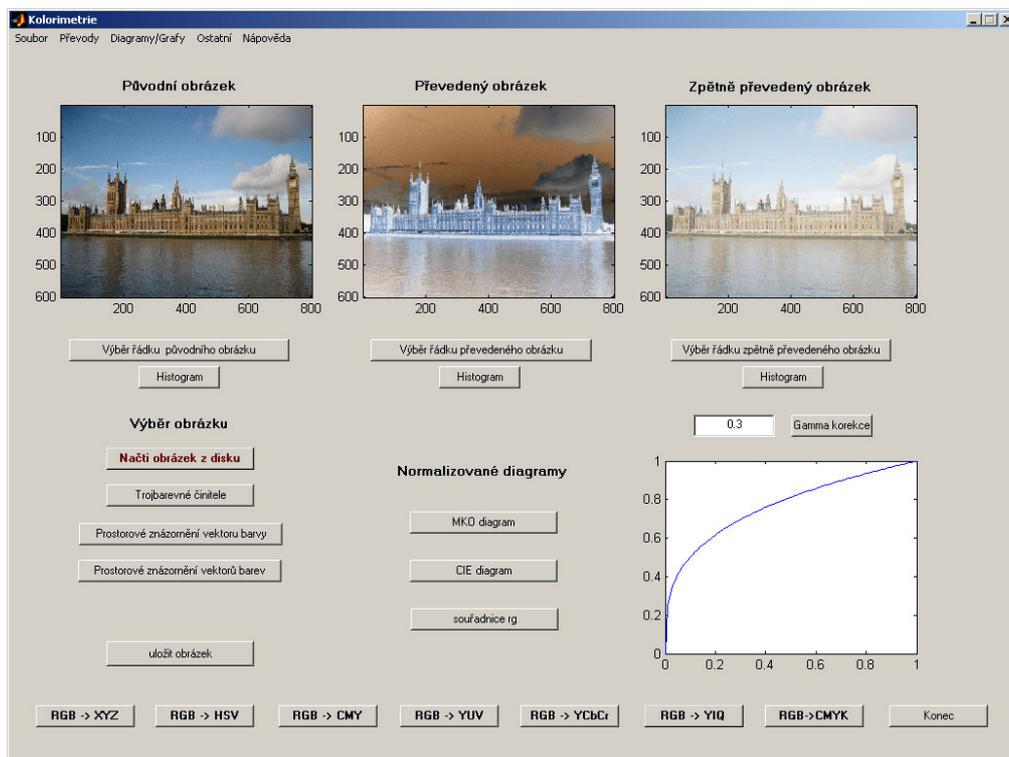
$$\begin{bmatrix} C \\ M \\ Y \end{bmatrix} = \begin{bmatrix} 1 - R \\ 1 - G \\ 1 - B \end{bmatrix} \quad (9)$$

$$\begin{bmatrix} R' \\ G' \\ B' \end{bmatrix} = \begin{bmatrix} 1 + C \\ 1 + M \\ 1 + Y \end{bmatrix} \quad (10)$$

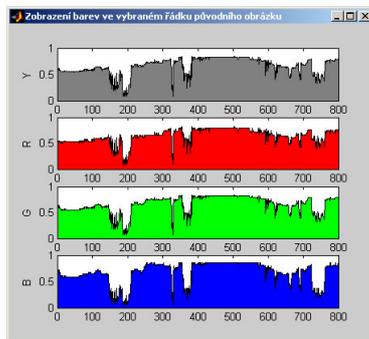
- CMYK color space – The component  $K$  (black) represents black as a fourth color.

$$\begin{bmatrix} K \\ C \\ M \\ Y \end{bmatrix} = \begin{bmatrix} \min(C, M, Y) \\ \frac{C - K}{1 - K} \\ \frac{M - K}{1 - K} \\ \frac{Y - K}{1 - K} \end{bmatrix} \quad (11)$$

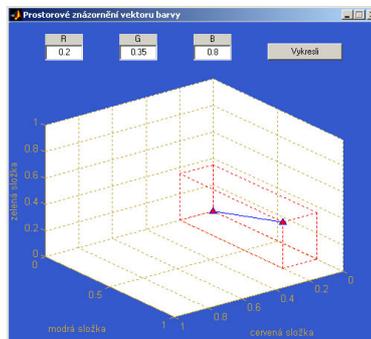
$$\begin{bmatrix} R' \\ G' \\ B' \end{bmatrix} = \begin{bmatrix} 1 + C \\ 1 + M \\ 1 + Y \end{bmatrix} \quad (12)$$



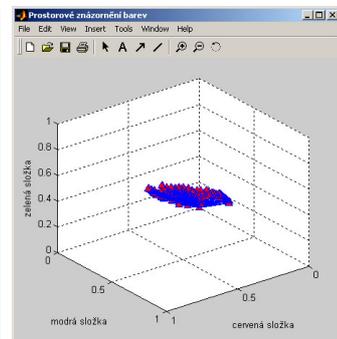
a) Graphical User Interface (GUI)



b) line selection (example)



c) RGB user defined color



d) RGB colors of picture

Figure 3: *Color\_Spaces* application for television colorimetry analysis applied in Matlab.

### 3 Color\_Spaces - application applied in Matlab

The application called *Color\_Spaces* (see Figure 3a) [8] is used for television colorimetry and various color spaces analysis. It contains well-arranged GUI (Graphical User Interface) for loading and saving of any color image in RGB representation and television resolution (720 x 576 pixels and 24 bit color depth). Then the input picture can be converted into desired color space (*RGB to XYZ, HSV, CMY, YUV, YCbCr, YIQ, CMYK*) and all three pictures (original, transformed and backward transformed) are displayed on the screen. All pictures can be saved on the disc and used for further analysis. The main functions after the transformation are:

- MKO diagram – analysis of chromaticity diagram of picture in coordinates  $x, y$  (normalized),
- CIE diagram – analysis of chromaticity diagram of picture in coordinates  $u, v$  (differences),
- RG diagram - analysis of chromaticity diagram of picture in coordinates  $r, g$  (saturation in %),
- 3D graph of all three *RGB* components of analyzed picture (see Figure 3d),
- 3D graph of all three *RGB* components of user defined color (see Figure 3c),
- Interactive line of the picture selection and  $Y, R, G, B$  waveform display (see Figure 3b),
- Histogram of all pictures (original, transformed and backward transformed),
- Trichromatic components of nonphysical colors display,
- Gamma correction application on backward transformed picture (see Figure 3a).

### 4 Evaluation of test pictures color characteristics

Color characteristics of 6 various test pictures used for modern compress methods picture quality evaluation at CTU Prague were obtained using the *Color\_Schemes* application. Results are presented in Figure 4 to Figure 9. It contains comprehensible summary of a) picture in spatial domain, b) *RGB* colors of picture in 3D area, c) MKO diagram, d) CIE diagram, e) RG diagram, f) histogram of the picture. It is easy to see differences between test pictures with different features: structured real picture (*Christines*) with details (*Square, Garden*) and textures (*Posters*), picture with large color areas (*Fruits*) combined with artificial parts, variable spatial and frequency activity (*Generator*) etc. [9]

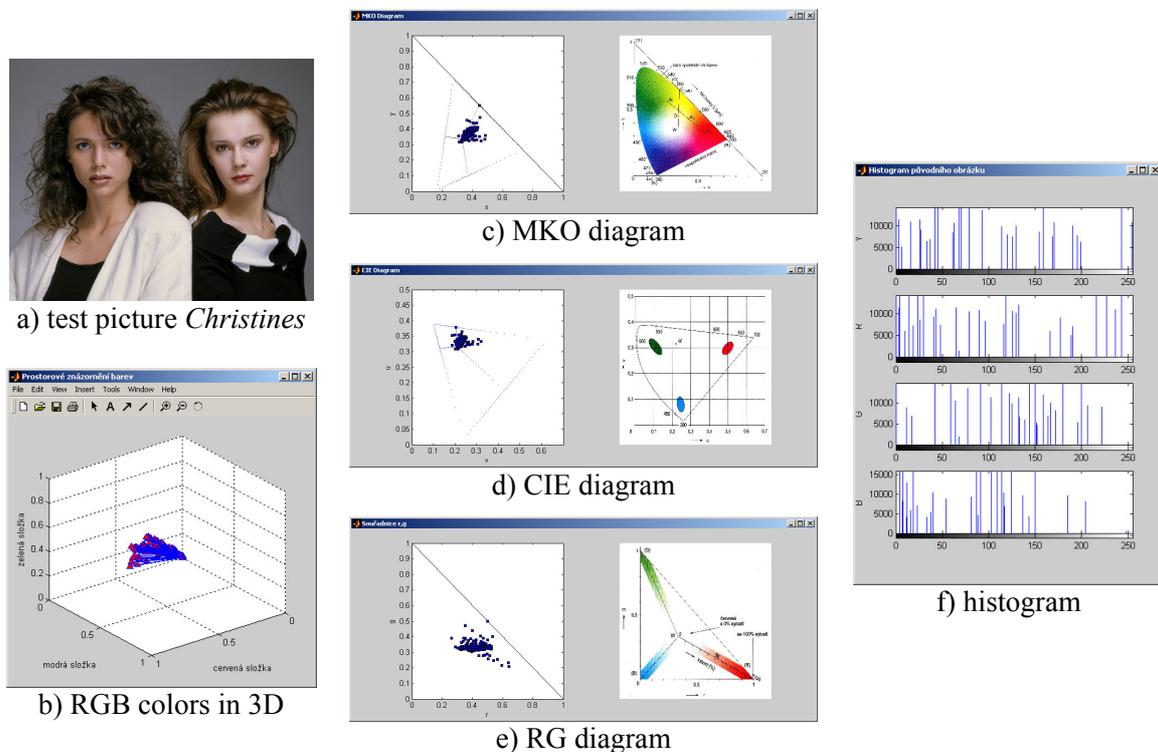
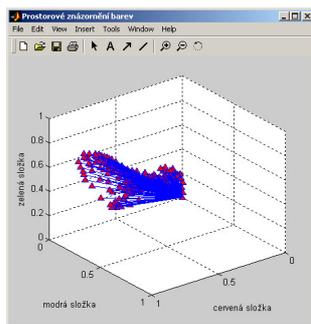


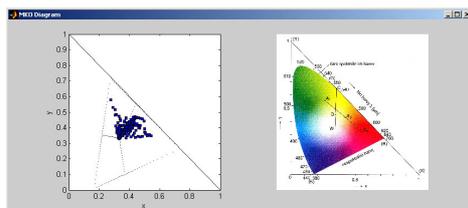
Figure 4: Evaluation of test picture *Christines* color characteristics.



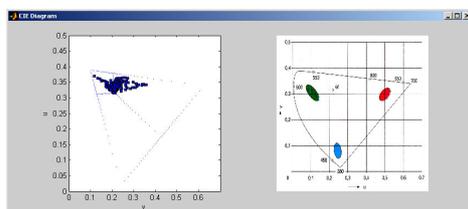
a) test picture *Fruits*



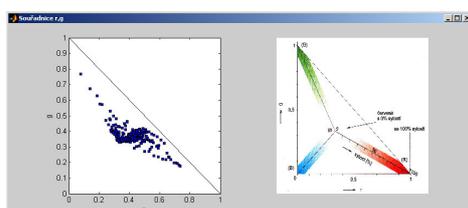
b) RGB colors in 3D



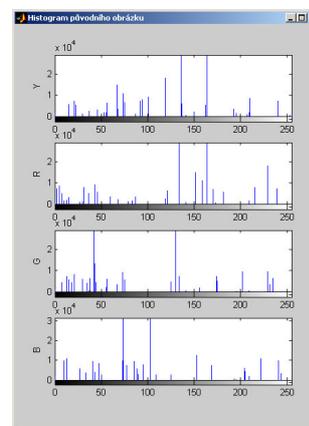
c) MKO diagram



d) CIE diagram



e) RG diagram

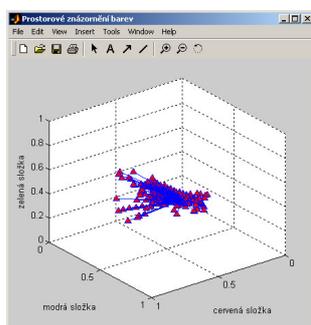


f) histogram

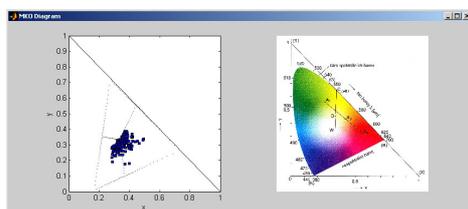
Figure 5: Evaluation of test picture *Fruits* color characteristics.



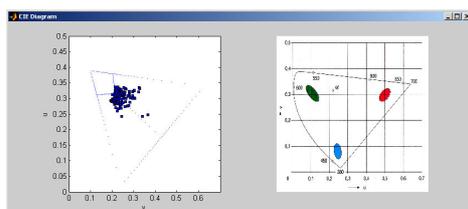
a) test picture *Square*



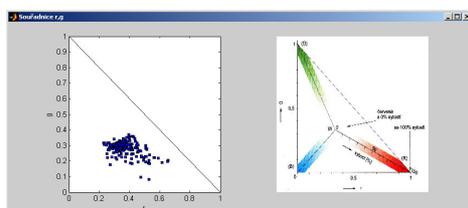
b) RGB colors in 3D



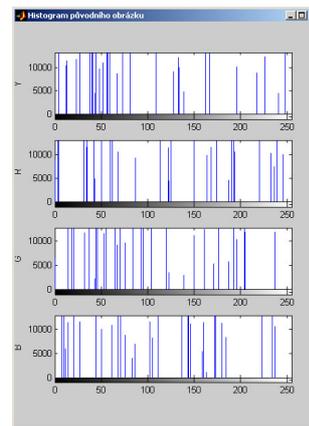
c) MKO diagram



d) CIE diagram



e) RG diagram

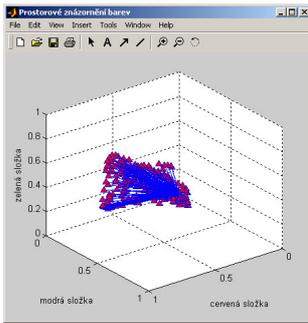


f) histogram

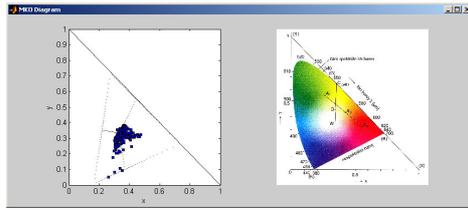
Figure 6: Evaluation of test picture *Square* color characteristics.



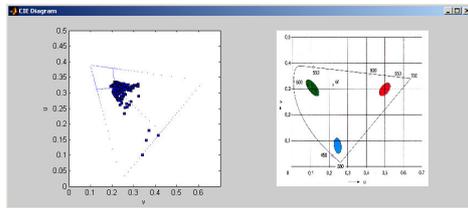
a) test picture *Posters*



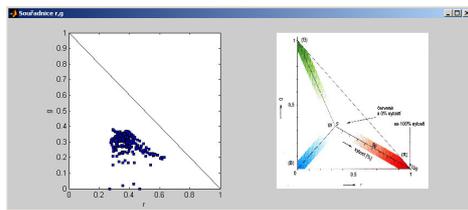
b) RGB colors in 3D



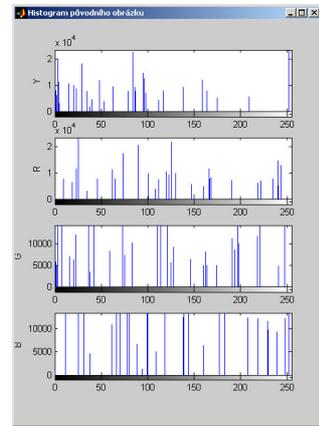
c) MKO diagram



d) CIE diagram



e) RG diagram

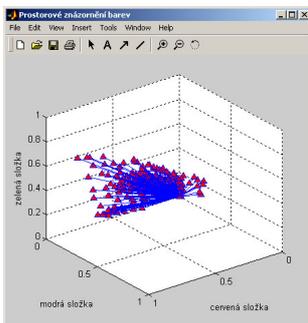


f) histogram

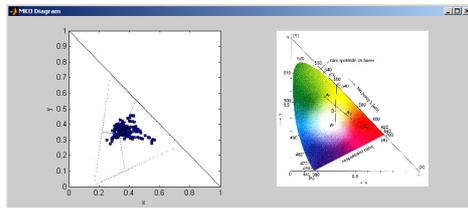
Figure 7: Evaluation of test picture *Posters* color characteristics.



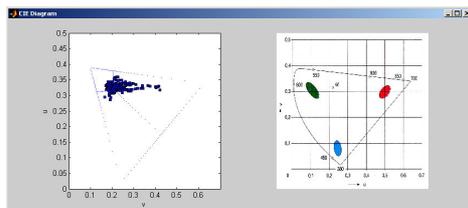
a) test picture *Garden*



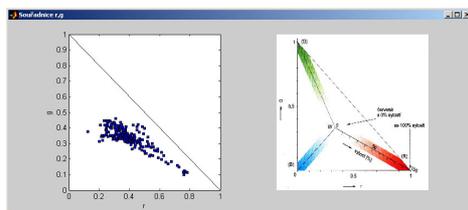
b) RGB colors in 3D



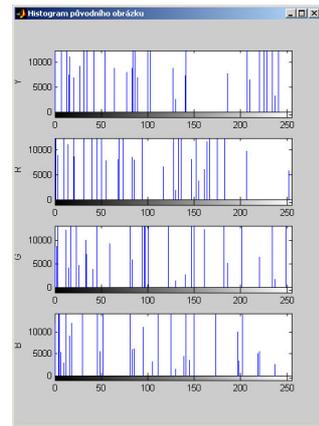
c) MKO diagram



d) CIE diagram



e) RG diagram



f) histogram

Figure 8: Evaluation of test picture *Garden* color characteristics.

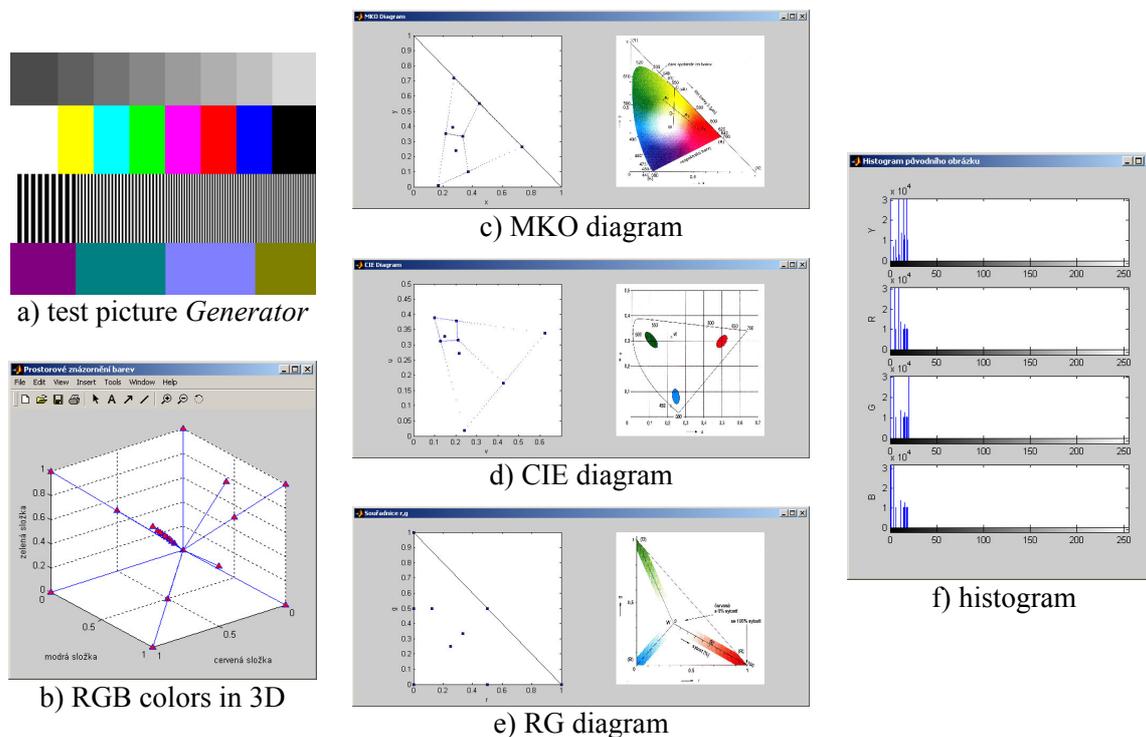


Figure 9: Evaluation of test picture *Generator* color characteristics.

## 5 Conclusion

Presented application *Color\_Spaces* was developed at Institute of radio Electronics Brno University of Technology and it is aimed into area of television colorimetry analysis of test pictures.

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