Color Measurement and Color Spaces Analysis for TV Using the (Commission International D'Éclairage) CIE System Evaluation

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Abstract:

Color is a perceived phenomenon and not a physical dimension like length or temperature, although the electromagnetic radiation of the visible wavelength spectrum is measurable as a physical quantity. A suitable form of representation must be found for storing, displaying, and processing color images. This representation must be well suited to the mathematical demands of a color image processing algorithm, to the technical conditions of a camera, printer, or television, and to human color perception as well. These various demands cannot be met equally well simultaneously. For this reason, differing representations are used in color image processing according to the processing goal. Color spaces indicate color coordinate systems in which the image values of a color image are represented. The standard color system, established by the International Lighting Commission CIE (Commission Internationale de I 'Eclairage), will be described. This system represents the international reference system of color measurement. The contribution deals with the Matlab application used for television and color spaces analysis. 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. The application allows selection of input color image, direct and backward transformation into the selected space including CIE diagram picture analysis and NTSC system. The additional functions of this research are evaluation of histogram of colors. The Color Spaces application outputs are introduced on various test pictures.
Keywords: CIE, Color Spaces, RGB, image analysis.

مقياس اللون وتحليلات فراغات لون العارض المرئي باستخدام معيار نظام لجنة الإضاءة الدولية

الخلاصة

اللون يدرك كظاهرة وليس بعد طبيعي مثل الطول أو درجة الحرارة، بالرغم من أن الإشعاع الكهرومغناطيسي لطيف طول الموجة المرئي قابل للقياس ككمية طبيعية. يجب أن يوجد شكل مناسب من التمثيل للخزن، العرض، و معالجة الصور الملونة. هذا التمثيل يجب أن يكون مناسب بشكل جيد جدا إلى المتطلبات الرياضية لخوارزمية معالجة الصورة ، إلى الشروط التقنية لآلة التصوير، الطابعة، أو العارض المرئي، وإلى فهم اللون لدى الإنسان أيضا. هذه المتطلبات المختلفة لا يمكن أن تجتمع جيّدا على حد سواء بشكل آني. لهذا السبب، يختلف التمثيل المستعمل في معالجة الصورة الملونة طبقا لهدف المعالجة. تشير فراغات اللون إلى أنظمة لون المنسّقة التي تكون قيم الصورة فيها ممثّلة. نظام اللون القياسي، أسّس بمعيار لجنة الإضاءة الدولية (CIE)،الذي سيتم وصفه يمثّل نظام الإشارة الدولي لمقياس اللون. تتعامل المحاكاة لهذا النظام مع تطبيق (Matlab) حيث تم استخدامها للتلفزيون و تحليلات اللون. كلّ فراغات اللون يمكن أن تشتقّ من معلومات RGB المجهّزة من قبل الأدوات مثل آلات التصوير والنواسخ الضوئية. يسمح التطبيق لاختيار الصورة الملونة ثم بعد ذلك تحليلها إلى الفضاء (CIE) وكذلك إلى نظام (NTSC) . إنّ الوظائف الإضافية الأخرى للبحث كانت في تقييم المدرج الإحصائي للألوان. نواتج التطبيق في تحليلات اللون المقدّمة انطبقت على صور الاختبار المختلفة.

الكلمات الدالة: لجنة الإضاءة الدولية ، فضاء الألوان ، الألوان الأساسية ،تحليل الصورة .

List of abbreviations

CIE Commission Internationale d' Éclairage
E(λ) spectral composition
HSB Hue Saturation Brightness
NTSC (National Television System Committee)
PAL (Phase Alternation Line)
RGB Red Green Blue
SECAM (Sequentiel Couleur Avec Mémoire or Sequential Color with Memory)
XY Z tri-incentive spectral colors in CIE system
YIQ color space derived from the *YUV* color space used by the NTSC system
YUV color space is used by the PAL system

Introduction

The CIE (*Commission Internationale d' Éclairage*) color system represents an international consensus. This system of colors has been used in radiometric studies in order to characterize soils. With this new technique for the spectroscopic image, the spatial distribution of CIE values can be obtained with greater accuracy. The color equation to radiometric data in terms of red, green and blue, for human vision involves negative values, which hinders its use. With the adoption of the CIE system, the occurrence of negative values is eliminated. However, it generates a virtual system that doesn't clearly translate to the behavior of the human eye (see figure1). The curves of the tri-stimulus of primary CIE in relation to wavelength are presented in figure 2.

The procedure to derive a color specifies the tri-incentive spectral colors (X, Y and Z) starting from a spectral composition E(λ). It can be algebraically expressed in the following way; and the chromaticity coordinate x, y and z is expressed by:

$$\mathbf{X} = \sum \mathbf{E}\lambda * \overline{\mathbf{X}}\lambda \quad \text{..................(1)}$$

$$Y = \sum E\lambda * \overline{Y}\lambda \quad \text{...............(2)}$$

$$Z = \sum E\lambda * \overline{Z}\lambda \quad \text{...............(3)}$$

Note that through the use of *X*, *Y*, and *Z*, we can now define a color of wavelength λ where *x*, *y*, and *z* are the amounts of the primaries *X*, *Y*, and *Z* (chromaticity coordinate). These three values represent relative proportions that can be normalized to obtain the values of *X*, *Y*, and *Z* as follows: [1]

$$x = \frac{X}{X+Y+Z} \quad \text{.....................(4)}$$

$$y = \frac{Y}{X+Y+Z} \quad \text{......................(5)}$$

$$z = \frac{Z}{X+Y+Z} \quad \text{.......................(6)}$$

The z value, once it can be obtained from x and y.**1 = x + y + z, 1 – z = x+ y**

Chromaticity Diagrams

It is advantageous for a two-dimensional graphic representation to merely present an intersecting plane of the three-dimensional color space in a *chromaticity diagram.* Since all color values, whose position vectors are linearly dependent, differentiate themselves solely by brightness, simply the brightness information is lost. The color information that remains through elimination of brightness is indicated as *chromaticity.* In other words, chromaticity is defined by hue and saturation (without brightness). The commonly related intersection plane for the construction of the chromaticity diagram in the *RGB* cube is the unit plane $R + G + B = 1$, whereby an equilateral triangle results (see Fig. 3). This triangle is also known as the *Maxwell color triangle*, which dates back to the 18th century and provides an easy-to-use method to define color mixing. Thus, prior to discussing the CIE system, let's first turn our attention to the Maxwell triangle. *M* is the intersection between the observed color position vector and the unit plane. Using the Newtonian gravity formulation the following relationships result for a color *M*,

$$r_M = \frac{R}{R+G+B},\ g_M = \frac{G}{R+G+B},\ \text{and}\ b_M = \frac{B}{R+G+B}.$$

---(7)

Where $rM + gM + bM = 1$………..(8)

However, the Cartesian representation with *r* as abscissa and *g* as ordinate, by which blue lies in the origin, is more commonly used. The above relationships do not change by this. As an example of such a representation, the chromaticity diagram for the 2" CIE standard observer is shown in Fig.4, in which two (of three) 2" *chromaticity coordinates*, namely x and *y* , are represented. The position of the spectral colors from 400 - 700 nm is listed as *spectral color transmission.* The connection of the endpoints is called the *purple boundary.* All real chromaticity's lie in the middle. The point that represents the equienergy spectrum ($x = y = z = 1 / 3$), is indicated by *E* see figure 4. [2]

Note that the three primary colors (green, blue, and red) are placed at the vertices of an equilateral triangle. Along the sides of a Maxwell triangle, mixing of two of the three primary color components occurs in every possible proportion. As you travel toward the center of the triangle, the third primary color becomes increasingly important, with the center of the triangle having a true white color. If we route a line through the center from each primary color vertex to the opposite side of the triangle, we obtain the positions where cyan, yellow, and magenta occur.

Although the Maxwell triangle shows the quality aspects of colors known as chromaticity, which denotes hue and saturation, it does not indicate the quantity aspects of color in terms of the effective amount of light. In addition, although the triangle provides an excellent hue representation, it lacks providing a match for saturation as you compare points around the sides of the triangle. Obtaining a match of saturation levels requires the dilution of spectral color with the third primary. For example, the center point on the blue–green edge of the triangle is not as saturated as the spectral cyan. Thus, to make the two colors the same, the addition of the third primary color, red, is required. In mathematical terms, this is equivalent to adding negative red to the color in the triangle, which moves the point outside the triangle. If this process is continued for every spectral hue, the result is a curve known as the spectral locus. This curve shows that some of the colors reside outside the triangle.

To get around this problem, the CIE used primaries that are not found in the spectrum. In doing so, the CIE selected three primaries that they called *X*, *Y*, and *Z*, which are theoretically defined as supersaturate colors; they reside outside the bounds of the spectral locus see (figure 5). [3]

The CIE chromaticity chart shown in the (figure 6) characterizes colors by a luminance parameter (Y) and two color coordinates (X and Y) which specify a point on the chart .The *x*- and *y*-axis values shown in Figure 6 represent the mapping of human color perception in terms of the CIE *x* and *y* parameters. The gamut of human color vision can be roughly described on the CIE chart however, doing so would be an approximation, and this author suggests that the use of wavelengths will provide a better indication of color. [3][4]

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 [2]. CIE defined standards for color matching functions and a diagram of chromaticity (see Figure 1) [3]. 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 Ycarries 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].

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 [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.

Color reproduction

The *YUV* color space is used by the PAL (Phase Alternation Line), NTSC (National Television System Committee), and SECAM (Sequential Couleur Avec Memoires 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 used three additional color information to display a color picture.

$$\begin{bmatrix} Y \\ U \\ V \end{bmatrix} = \begin{bmatrix} 0{,}299 & 0{,}587 & 0{,}114 \\ -0{,}147 & -0{,}289 & 0{,}436 \\ 0{,}615 & -0{,}515 & -0{,}100 \end{bmatrix} \cdot \begin{bmatrix} R \\ G \\ B \end{bmatrix} \quad \text{.........(9)}$$

$$\begin{bmatrix} R' \\ G' \\ B' \end{bmatrix} = \begin{bmatrix} 1 & 0 & 1{,}140 \\ 1 & -0{,}395 & -0{,}581 \\ 1 & 2{,}032 & 0 \end{bmatrix} \cdot \begin{bmatrix} Y \\ U \\ V \end{bmatrix} \quad \text{.......(10)}$$

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

$$\begin{bmatrix} Y \\ I \\ Q \end{bmatrix} = \begin{bmatrix} 0{,}299 & 0{,}587 & 0{,}114 \\ 0{,}596 & -0{,}275 & -0{,}321 \\ 0{,}212 & -0{,}523 & -0{,}311 \end{bmatrix} \cdot \begin{bmatrix} R \\ G \\ B \end{bmatrix} \quad \text{........(11)}$$

$$\begin{bmatrix} R' \\ G' \\ B' \end{bmatrix} = \begin{bmatrix} 1 & 0{,}956 & 0{,}621 \\ 1 & -0{,}272 & -0{,}647 \\ 1 & -1{,}107 & 1{,}704 \end{bmatrix} \cdot \begin{bmatrix} Y \\ I \\ Q \end{bmatrix} \quad \text{...........(12)}$$

The *XYZ* color space was set by *CIE* 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. [6]

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix} = \begin{bmatrix} 2{,}769 & 1{,}741 & 1{,}130 \\ 1 & 4{,}591 & 0{,}060 \\ 0 & 0{,}057 & 5{,}594 \end{bmatrix} \cdot \begin{bmatrix} R \\ G \\ B \end{bmatrix} \quad \text{.......(13)}$$

$$\begin{bmatrix} R' \\ G' \\ B' \end{bmatrix} = \begin{bmatrix} 2{,}365 & -0{,}896 & -0{,}468 \\ -0{,}515 & 1{,}425 & 0{,}005 \\ -0.014 & 0.010 & 1.009 \end{bmatrix} \cdot \begin{bmatrix} X \\ Y \\ Z \end{bmatrix} \quad \text{......(14)}$$

RGB Color Spaces

The most commonly employed color space in computer technology is the *RGB color space*, which is based on the additive mixture of three primary colors R, ***G*** **,** and **B** (see Section 3.1). The international standardized wave-lengths of the primary colors Red, Green, and Blue. It should be noted that the terms *red*, *green*, and *blue* were introduced solely for the purpose of standardization to provide descriptions for the primary colors. Visible colors and wavelengths are not equivalent. In order to avoid possible confusion, the notations *L* , *M*, ***S*** may be used for light containing long, middle, and short wavelengths instead of the notations *R*, *G*, *B*. However, the usual notations are *R*, *G*, and *B* and they will be used in the following.

The primary colors are for the most part the "reference colors" of the imaging sensors. They form the base vectors of a three-dimensional orthogonal (color)-vector space, where the zero-vector represents black (see Fig. 3.7). The origin is also described as *black point*. Any color can therefore be viewed as a linear combination of the base vectors in the *RGB* space. In one such accepted *RGB* color space, a color image is mathematically treated as a vector function with three components. The three vector components are determined by the measured intensities of visible light in the long-wave, middle-wave, and short-wave area. For a (three-channel) *digital color image* **C,** three vector components *R*, *G*, *B* are to be indicated for each image pixel *(x , y):*

$$\mathbf{C}(x,y) = \left(R(x,y), G(x,y), B(x,y)\right)^T = (R,G,B)^T. \quad \text{...(15)}$$

These values are referred to as tristimulus *values.* The colors that are represented by explicit value combinations of the vector components *R , G, B,* are relative, device-dependent entities. All vectors *(R , G, B)* with integer components $0 \leq R, G, B \leq G_{\max}$ characterize one color in the *RGB* color space. *Gmax* + 1 indicates the largest permitted value in each vector component. Using permeable filters in the generation of a color image in the *RGB* color space, so-called red, green, and blue extracts are generated in the long wave, middle wave and short wave area of visible light. If one refrains from using the filter, each of the three scanning's is identical with the digitalization of a gray-level image. The rational numbers:

$$r = \frac{R}{R+G+B}, g = \frac{G}{R+G+B}, \text{and } b = \frac{B}{R+G+B} \quad \ldots\ldots(16)$$

are the color value components that are normalized with respect to the intensity.

The RGB color space is the most applied computer-internal representation of color images. Its wide distribution is, among other things, traced back to the well standardized three primary colors. Almost all visible colors can be represented by a linear combination of the three vectors. For identical objects, differing color values are generated with different cameras or scanners since their primary colors in general do not match. The process of adjusting color values between different devices (e.g., camera RGB, monitor RGB, and printer RGB) is called *color management.* [7]

Results of Color Spaces and CIE Matlab Evaluation

The application called Color Spaces (see Figures 8,9,10) used for television colorimetric and various color spaces analysis. It contains RGB representation and television resolution (256 x 256 pixels and 24 bit color depth). Then the input picture can be converted into desired color space (*RGB* to *XYZ*, *YIQ*) and all three pictures (original, transformed and color histogram) are displayed on the screen. All pictures can be saved on the disc and used for further analysis. In the RGB color space, every vector inside the color cube represents exactly one color. The transformation depends on the image information contents.

Conclusions

The main advantages of the employment of the CIE color system are: spectral dimensionality reduction;, determination of chromatic values, which are easily understood by the human eye, allowing a cognitive interpretation; and establishment of values according to the international pattern that allows for comparisons among different areas. This characteristic is not obtained by other methods of dimensionality reduction such as the analysis of principal components and MNF (Minimum Noise Fraction - Green *).*Any three of the 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]. *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. It is easy to see differences between test pictures with different features: structured real picture (*board*) with details (*peppers*) and textures (*football*), picture with large color areas combined with artificial parts, variable spatial and frequency activity .

References:

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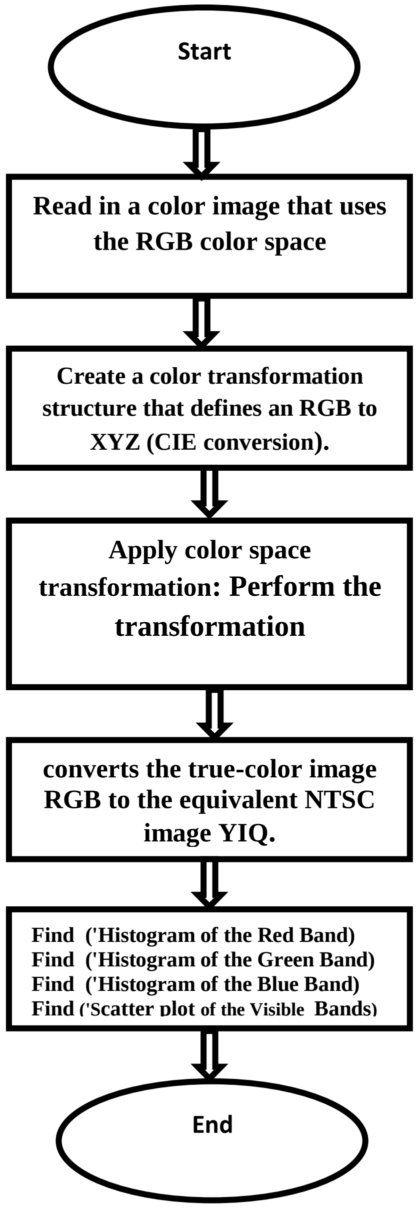
Appendex1

Matlab simulation program flow chart:



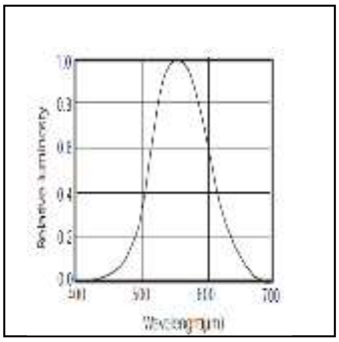


Figure 1. gives the brightness curve for the reference observer.

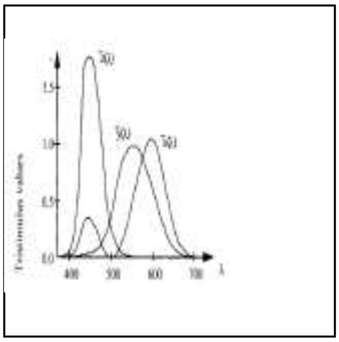


Figure 2. (CIE tri-stimulus values x, y, and z) for the spectral colors.

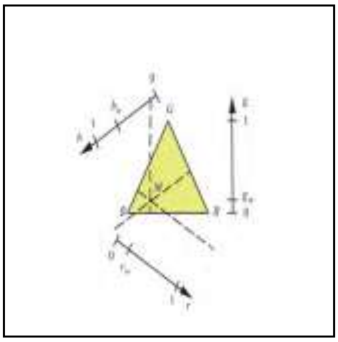


Figure 3. Maxwell color triangle represented as a chromaticity diagram

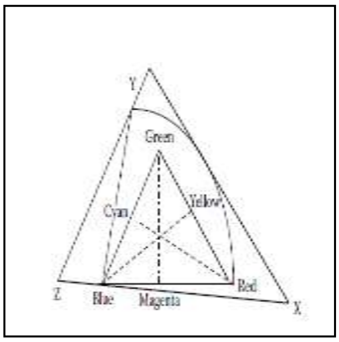


Figure 4. The CIE chromaticity:
(a) in numerical representati
(b) and (b) as color-coded illustration.

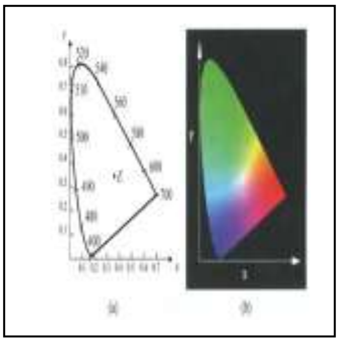


Figure 5. The CIE theoretical primaries and their relationship to the spectral locus

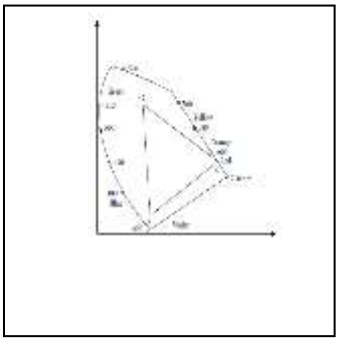


Figure 6. CIE chromaticity chart, showing wavelengths marked around the outside .

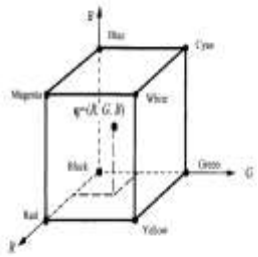
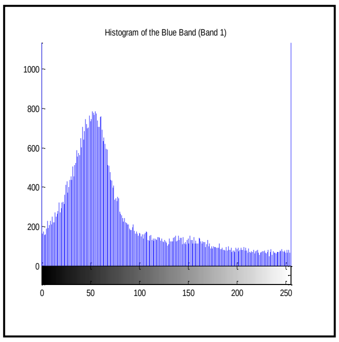


Figure 7. Visible colors RGB cube space.

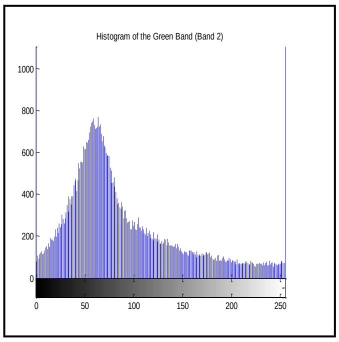
a) *RGB* picture

b) *XYZ* picture

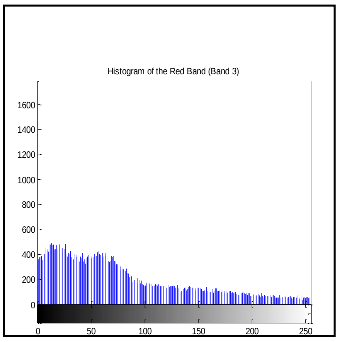
c) *YIQ* picture



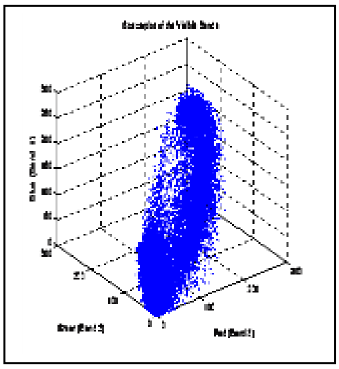
d)blue color histogram



e)green color histogram



f)red color histogram



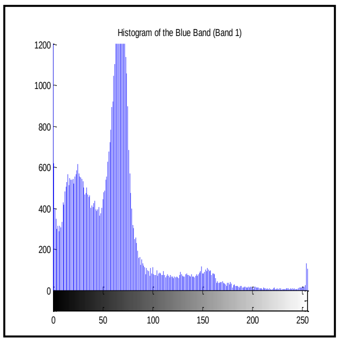
g) Scatterplot of the Visible colors RGB

Figure 8*: Color_Spaces* application for television colorimetry analysis applied in Matlab using Board test pictur

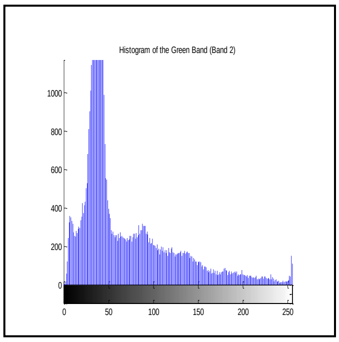
a) *RGB* picture

b) *XYZ* picture

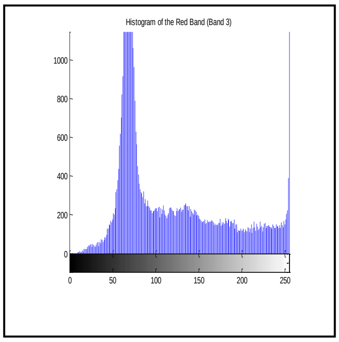
c) *YIQ* picture



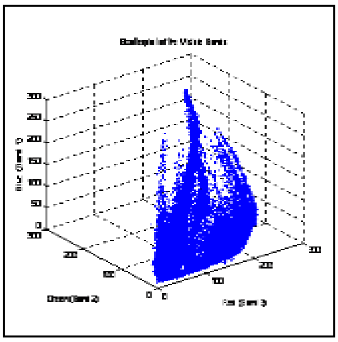
d)blue color histogram



e)green color histogram



f)red color histogram



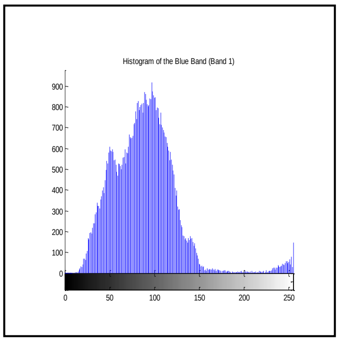
g) Scatterplot of the Visible colors RGB

Figure 9: *Color_Spaces* application for television colorimetry analysis applied in Matlab using Peppers test picture.

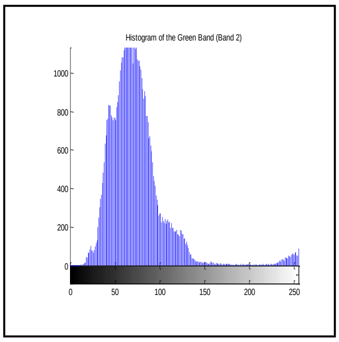
a) *RGB* picture

b) *XYZ* picture

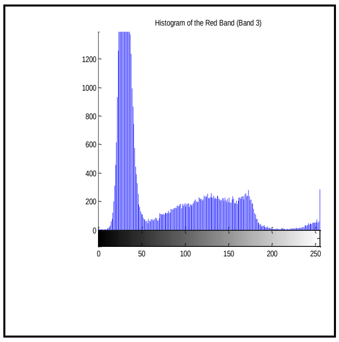
c) *YIQ* picture



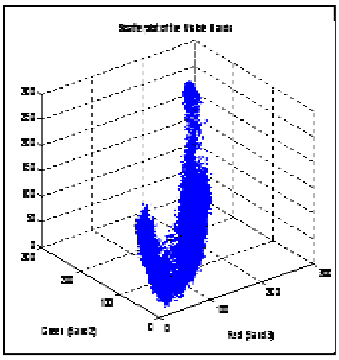
d)blue color histogram



e)green color histogram



f)red color histogram



g) Scatterplot of the Visible colors RGB

Figure10*: Color_Spaces* application for television color-imetry analysis applied in Matlab using Football test picture.