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Sub Pixel Analysis on Hypothetical Image by Using Colorimetry

Merugu Suresh, Kamal Jain

Abstract-- Color, more generally it is a signature associated to each object which makes it recognizable and is highly dependent on the nature of the light source, which can be either natural (sun) or artificial (light bulbs). As the perception of color involves a complex processing by the brain, and could not be restricted to something like "the spectrum of the light captured by the human eye". The increased use of color has brought with its new challenges. In order to meaningfully record and process color images, it is essential to understand the mechanisms of color vision and the capabilities and limitations of color imaging devices. It is also necessary to develop algorithms that minimize the impact of device limitations and preserve color information as images are exchanged between devices. The colours in real world have sharp boundaries we know exactly where a colour starts and where it ends. But when we take image of such an area the image is expressed in pixels, each pixel representing one value often should be a grey value in each band. These pixels don't express the boundaries exactly as sharp as they are in reality; we observe a transition from one colour to some colour other than the second colour.

Key Words: Colorimetry, CIE Chromaticity Diagram, Tristimulus values, Pixel Analysis, Statistical Measures, Spectral colors, Color Matching Function.

I. INTRODUCTION

Colorimetry is a branch of color science pertaining to the measurement and numerical specification of the color of visual stimuli. Since perceived color is a property of the human eye and brain, and not a property of physics [27], colorimetry is inextricably linked to the underlying biology of vision. We describe the light reaching the eye from an image location by its spectral power distribution. The spectral power distribution generally specifies the radiant power density at each wavelength in the visible spectrum. For human vision, the visible spectrum extends roughly between 400 and 700 nm [7]. Depending on the viewing geometry, measures of radiation transfer other than radiant power may be used. These measures include radiance, irradiance, existence, and intensity.

Color and color perception are limited at the first stage of vision by the spectral properties of the layer of light-sensitive photoreceptors that cover the rear surface of the eye (upon which an inverted image of the world is projected by the eye's optics). These photoreceptors transducer arriving photons to produce the patterns of electrical signals that eventually lead to perception.

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* Correspondence Author
Merugu Suresh, Research Scholar, Department of Civil Engineering, Indian Institute of Technology (IIT) Roorkee, Uttarakhand, India.
Dr. Kamal Jain, Professor, Department of Civil Engineering, Indian Institute of Technology (IIT) Roorkee, Uttarakhand, India.

Daytime (photopic) color vision depends mainly upon the three classes of cone photoreceptor, each with different spectral sensitivity.

These are referred to as long-, middle-, and short-wavelength-sensitive cones (L, M and S cones), according to the part of the visible spectrum to which they are most sensitive. Night-time (scotopic) vision, by contrast, depends on a single class of photoreceptor, the rod [1].

II. COLOR MATCHING

The basis of the trichromatic theory of color vision is that it is possible to match an arbitrary color by superimposing appropriate amounts of three primary colors. In an additive color reproduction system such as color television, the three primaries are individual red, green, and blue light sources that are projected onto a common region of space to reproduce a colored light. In a subtractive color system, which is the basis of most color photography and color printing, a white light sequentially passes through cyan, magenta, and yellow filters to reproduce a colored light.

One has to make a difference between additive color mixing, which is the mixing of different colored light beams, and subtractive color mixing, which deals with the removal of a given part of the incident light spectrum by, for instance, colored pigments.

2.1 Additive and Subtractive Color Matching

Generally speaking, all the color matching all the color matching techniques can be classified into two groups additive and subtractive. In additive color matching, color is produced as an additive mixture of light of different wavelengths, known as primary colors. Typically, the additive primaries are red, green and blue (RGB). The principle of additive color mixture [2] is illustrated in the figure shown below, where mixing red with green light produces yellow, similarly, red and blue produces magenta, blue and green forms cyan and the mixture of all three primaries gives white. Additive color matching is typically used for emissive displays, such as CRT and LCD displays.

Subtractive color matching, typically used for transparent or transmissive media, produces colors by blocking/removing spectral components from white light through light absorption. The most common subtractive primaries are cyan, magenta and yellow (CMY), colorants that absorb light in the red, green and blue spectral bands of the spectrum, respectively. The principle is illustrated in the figure shown below, where the overlay of cyan and magenta producing blue, cyan and yellow produces green, magenta and yellow produces red and the overlay of all three colorants results in black. It is common to add a fourth black (K) colorant, to improve the reproduction of gray tones and allowing for darker colors to be reproduced (Sharma 2003).

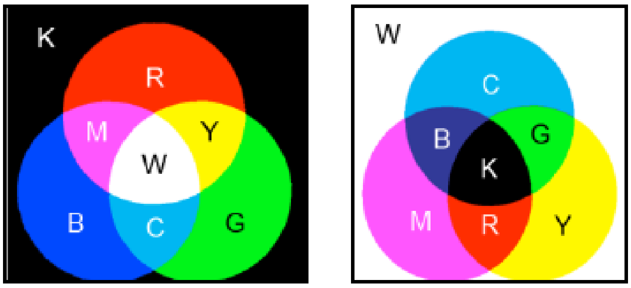

Figure1: a) Additive Color Matching, b) Subtractive Color Matching

III. REVIEW ON EXISTING COLOR-MATCHING FUNCTIONS

The available color-matching data and functions (and as a result, the cone spectral sensitivities derived from them) vary considerably in quality. In this section, five sets of data are discussed. The most commonly used are not necessarily the best at predicting normal color matches. The luminosity function, V(λ), which has been artificially linked to the CIE CMFs, is also discussed.

3.1 CIE (1931) 2-deg CMFs

The most widely used CMFs are the CIE (1931) 2-deg CMFs [27], which are based on color-matching data obtained by Wright [26] and Guild [13]. Those data, however, are relative data, which give only the ratios of the three primaries required to match spectral test lights. Although sufficient for chromaticity coordinates, knowledge of the absolute radiances of the matching primaries is required to generate CMFs. The CIE attempted to reconstruct this information by assuming that a linear combination of the three unknown CMFs must equal the 1924 CIE V(λ) function [4, 6]. In addition to uncertainties about the validity of this assumption [20], the V(λ) curve that was used is far too insensitive at short wavelengths [see Fig. 13 of [23].

3.2 Judd, Vos-modified CIE 2-deg CMFs

In an attempt to correct the CIE 1924 V(λ) function, Judd [15] increased the sensitivity of V(λ) below 460 nm, and derived a new set of CMFs also based on the Wright and Guild data (see Wyszecki & Stiles [27] Table 1 (5.5.2)), which were later slightly modified by Vos [18, Table 1]. These CMFs are in common use in vision research as their transformation; the Smith–Pokorny cone fundamentals.

The substantial modifications to the V(λ) function introduced by Judd had the un-wanted effect of producing CMFs that are relatively insensitive near 460 nm (where they were unchanged). Although this insensitivity can be roughly characterized as being consistent with a high macular pigment density [18, 22, 28], the CMFs are somewhat artificial and thus removed from real color matches.

3.3 Stiles & Burch (1955) 2-deg CMFs

The assumption that V(λ) is a linear combination of the CMFs is entirely unnecessary, since CMFs can be measured without any recourse to photometric data. The Stiles & Burch [22] 2-deg CMFs are an example of directly measured functions. Though referred to by Stiles as ''pilot'' data, these CMFs are the most extensive set of directly measured color-matching data for 2-deg vision available, being averaged from matches made by ten observers. Even compared in relative terms, there are real differences between the CIE 1931 and the Stiles & Burch [22] 2-deg color-matching data in the range between 430 and 490 nm [see Fig. 1of [22]. These CMFs are seldom used.

3.4 Stiles & Burch (1959) 10-deg CMFs

The most comprehensive set of color-matching data are the large-field, centrally viewed10-deg CMFs of Stiles &Burch [22]. Measured in 49 subjects from approximately 390 to 730 nm (and in 9 subjects from 730 to 830 nm), these data are probably the most secure set of existing CMFs. Like the Stiles &Burch [22] 2-deg functions, the 10-deg functions represent directly measured CMFs, and so do not depend on measures of V(λ). These CMFs are the basis of the Stockman and Sharpe [28].

3.5 CIE (1964) 10-deg CMFs

The large field CIE 1964 CMFs are based mainly on the 10-deg CMFs of Stiles & Burch [22], and to a lesser extent on the arguably inferior and possibly rod-contaminated 10-deg CMFs of Speranskaya [19]. While the CIE 1964 CMFs are similar to the 10-deg CMFs of Stiles & Burch (1959), they differ in several ways that compromise their use as the basis for cone fundamentals [28].

3.6 Luminance and the Luminosity Function, V(λ)

The CIE combined luminosity functions for 2-deg [V(λ) or y'(λ)] or 10-deg [(V10(λ) or y'10(λ)] vision with color-matching data by making one of the CMFs equal to the luminosity function. It should be recognized, however, that luminosity functions are quite distinct from CMFs and cone fundamentals. In particular, the shapes of luminosity functions change with chromatic adaptation [22, 23], whereas the CMFs and cone spectral sensitivities do not (until bleaching levels). Biologically, the cone spectral sensitivities are receptoral, whereas the luminosity function is post receptoral.

V(λ) is a photometric measure of luminous efficiency or spectral sensitivity that is defined as the effectiveness of lights of different wavelength in specific photometric matching tasks, which today are usually heterochromatic flicker photometry (HFP), in which rapidly alternating lights are matched in intensity to eliminate the perception of flicker, or a version of side-by-side matching, in which the relative intensities of the two half fields are set so that the border between them appears ''minimally distinct'' (MDB). These tasks are favored because they produce, in contrast with some of the methods used to obtain the 1924 V(λ), additive results [20, 25]. It should be noted that luminance does not define how bright things actually appear. Fields that are equal in luminance often differ substantially in apparent brightness. There is no a priori reason why colorimetric data should depend on photometric data, as was the case for the CIE 1931 functions. Given modern calibration methods, there is no justification for using photometric data to alter or adjust colorimetric data.

IV. COLORIMETRY

Colorimetry is the science of measuring, representing, and computing color in a way that takes into account the interaction between the physical aspects of color and the physiological aspects of human vision.

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The basis of colorimetry is a set of standards defined by Commission Internationale de l Eclariage (CIE), the primary organisation for the standardization of colorimetry and terminology [7].

The sensory expression of color is thus dependent on the interaction of three different elements: a light source, an object and an observer. This involves both physical aspects of color, such as the spectral interaction between the light and the object, and physiological aspects of human vision. The interaction between these two aspects, the psychophysical aspect, dealing with the relation between physical attributes and the resulting sensations, is defined by colorimetry [Hardeberg 2001].

4.1 Now what colour theory has to say?

Colour is the brains reaction to a specific visual stimulus. Although we can precisely describe colour by measuring its spectral power distribution (the intensity of the visible electro-magnetic radiation at many discrete wavelengths) this leads to a large degree of redundancy. The reason for this redundancy is that the eye's retina samples colour using only three broad bands, roughly corresponding to red, green and blue light. The signals from these colour sensitive cells (cones), together with those from the rods (sensitive to intensity only), are combined in the brain to give several different "sensations" of the colour.

4.2 What is the CIE System?

The CIE has defined a system that classifies colour according to the HVS (the human visual system). Using this system we can specify any colour in terms of its CIE co-ordinates and hence be confident that a CIE defined colour will match another with the same CIE definition. The CIE has measured the sensitivities of the three broad bands in the eye by matching spectral colours to specific mixtures of three coloured lights. The spectral power distribution (SPD) of a colour is cascaded with these sensitivity functions to produce three tri-stimulus values. These tri-stimulus values uniquely represent a colour, however since the illuminant and lighting and viewing geometry will affect the measurements these are all carefully defined. The three CIE tri-stimulus values are the building blocks from which many colour specifications are made.

A colour can be described as a mixture of three other colours or "Tristimuli". Typically RGB for CRT based systems (TV, computer) or XYZ (fundamental measurements). The amounts of each stimulus define the colour. However, it is frequently useful to separate the colour definition into "luminance" and "chromaticity". Lower case is always used to signify chromaticity coordinates; upper case always signifies tristimulus values (or amounts of the primaries). Chromaticity co-ordinates can be plotted on a two-dimensional diagram that defines all the visible colours, luminance is normal to that diagram [4].

The CIE XYZ (1931) system is at the root of all colorimetry. It is defined such that all visible colours can be defined using only positive values, and, the Y value is luminance. Consequently, the colours of the XYZ primaries themselves are not visible. The chromaticity diagram (figure) is highly non-linear, in that a vector of unit magnitude representing the difference between two chromaticities is not uniformly visible. A colour defined in this system is referred to as Yxy. A third co-ordinate, z, can also be defined but is redundant since x+y+z=1 for all colours.

$$x = X/(X+Y+Z) \qquad \text{... (1)}$$

$$y = Y/(X+Y+Z) \qquad \text{... (2)}$$

Also we have relation between RGB and XYZ which is given as:

$$\begin{pmatrix} R \\ G \\ B \end{pmatrix} = \begin{pmatrix} 3.240 & -1.537 & -0.498 \\ -0.969 & 1.876 & 0.042 \\ 0.056 & -0.204 & 1.057 \end{pmatrix} \begin{pmatrix} X \\ Y \\ Z \end{pmatrix} \qquad \text{... (3)}$$

So we can convert from one colour space to other using such relations. But in this project we are concerned with RGB to XYZ and further to x, y chromaticity diagram. The chromaticity diagram contains infinite number of colours and each colour can be obtained by infinite number of combinations just it is combination of two colours (wavelength) in a proportion, since line joining two wavelengths contains infinite number of points and if we know the proportion of mixing then we can get to point.

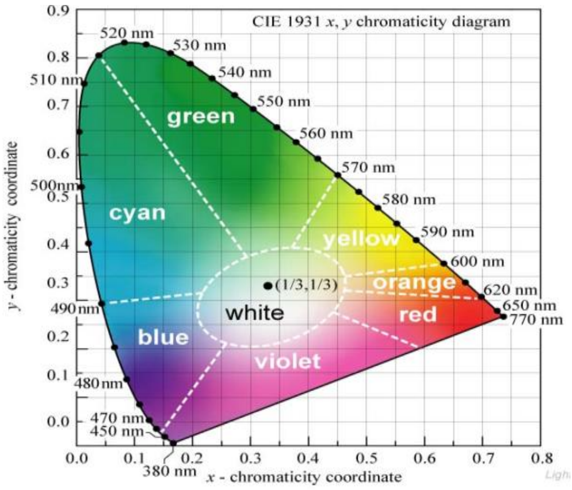

Figure2: CIE 1931 (x, y) chromaticity diagram.

V. APPROACH AND METHODOLOGY

5.1 Graphical Representation – Color Triangle

Polychromatic radiation with a luminance $Lc(\lambda)$ is associated with a color $C = RcR + GcG + BcB$ where the trichromatic coordinates in the RGB color system are given by:

$$R_c = \int L_c(\lambda)\overline{r(\lambda)}d\lambda$$

$$G_c = \int L_c(\lambda)\overline{g(\lambda)}d\lambda$$

$$B_c = \int L_c(\lambda)\overline{b(\lambda)}d\lambda$$

Since only the relative values of these coordinates have a physical meaning in terms of chromaticity, it is usual to introduce the trichromatic coordinates r, g and b given by:

$$r = \frac{R_c}{R_c + G_c + B_c}$$

$$g = \frac{G_c}{R_c + G_c + B_c}$$

$$b = \frac{B_c}{R_c + G_c + B_c}$$

In practice, it is easier to represent colors in a plane rather than in the 3-D space. We have, from:

$$r + g + b = 1$$

Which is the equation of a plane defined by the 3 terminal points of the unit vectors $\vec{R}$, $\vec{G}$ and $\vec{B}$.

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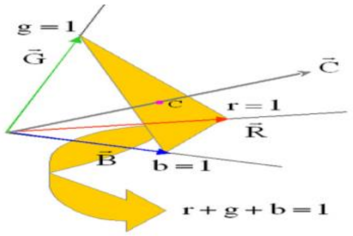

Figure3: The Color Triangle diagram.

A color $\vec{C}$ is then represented by a point (C) in that plane. Since the component b can be straightforwardly derived from (8) provided that r and g are known, one generally prefers to display the plane $r+g+b=1$ under the form of a right isosceles triangle in which r and g lie along the right axes of the triangle. The diagram obtained is called the (r, g) chromaticity diagram, displayed in figure 14. Monochromatic radiations (for $\lambda \in [380\text{nm}; 780\text{nm}]$) lie along the so-called spectrum locus.

They correspond to the following coordinates (with $L_e(\lambda)=\delta_\lambda$):

$$r=\frac{\bar{r}(\lambda)}{\bar{r}(\lambda)+\bar{g}(\lambda)+\bar{b}(\lambda)}$$
$$g=\frac{\bar{g}(\lambda)}{\bar{r}(\lambda)+\bar{g}(\lambda)+\bar{b}(\lambda)}$$
$$b=\frac{\bar{b}(\lambda)}{\bar{r}(\lambda)+\bar{g}(\lambda)+\bar{b}(\lambda)}$$

All existing colors have their associated points inside the domain delimited by the spectrum locus and the purple line. Points outside of this area have no physical meaning and do not correspond to real stimuli.

5.2 XYZ Color Space

As it can be seen on figure 14, many colors have negative trichromatic coordinates in the RGB system, as a result of the choice of three monochromatic primary colors.

In order to eliminate this drawback, a linear transformation over the RBG space is made, leading to the tristimulus values $\overline{x}(\lambda)$, $\overline{y}(\lambda)$ and $\overline{z}(\lambda)$ which take only positive values. Moreover, the primaries $\vec{X}$, $\vec{Y}$ and $\vec{Z}$ (no longer monochromatic) have been chosen in such a way that the plane $O\vec{X}\vec{Y}$ corresponds to a zero-luminance plane, and that the axis $O\vec{Y}$ becomes the axis of visual luminances. Indeed, for a stimulus having a luminance $L_e(\lambda)$ in energetic units, we know that the luminance in visual units $L_v(\lambda)$ is:

$$L_v(\lambda)=K_m\int L_e(\lambda).V(\lambda).d\lambda=Y$$

With $K_m=683\,lm/W$ (in photopic vision), where $V(\lambda)$ is the luminous efficiency function (refer to a basic photometry course to learn more about $V(\lambda)$).Using our usual trichromatic notations, we see that if we define the Y coordinate as $Y=K_m\int L_e(\lambda).\overline{y}(\lambda).d\lambda$ then $\overline{y}(\lambda)$ is identical to $V(\lambda)$, so that one of the trichromatic coordinates will give directly the visual luminance.

$$\left[\overline{r}(\lambda);\overline{g}(\lambda);\overline{b}(\lambda)\right]\rightarrow\left[\overline{x}(\lambda);\overline{y}(\lambda);\overline{z}(\lambda)\right]$$

The linear transformation is defined by []:

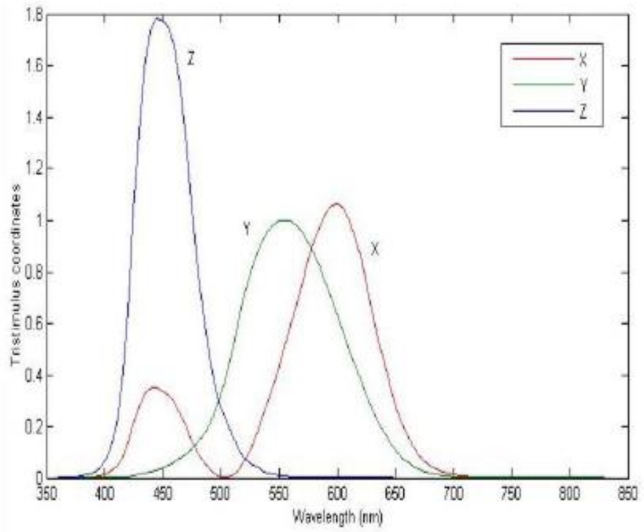

Figure4: Tristimulus Values XYZ CIE 1931 for used Sample Images.

Table1: Tristimulus Values XYZ CIE 1931 of the used Sample Image.

Wavelength	X	Y	Z
380	0.00026899	0.0002	0.01226
385	0.0053105	0.00039556	0.024222
390	0.010781	0.0008	0.04925
395	0.020792	0.0015457	0.095135
400	0.037981	0.0028	0.17409
405	0.063157	0.0046562	0.29013
410	0.099941	0.0074	0.46053
415	0.15824	0.011779	0.73166
420	0.22948	0.0175	1.0658
425	0.28108	0.022678	1.3146
430	0.31095	0.0273	1.4672
435	0.33072	0.032584	1.5796
440	0.33336	0.0379	1.6166
445	0.31672	0.042391	1.5682
450	0.28882	0.0468	1.4717
455	0.25969	0.052122	1.374
460	0.23276	0.06	1.2917
465	0.20999	0.072942	1.2356
470	0.17476	0.09098	1.1138
475	0.13287	0.11284	0.9422
480	0.091944	0.13902	0.75596
485	0.056985	0.16987	0.5864
490	0.031731	0.20802	0.44669
495	0.014613	0.25808	0.34116
500	0.0048491	0.323	0.26437
505	0.0023215	0.4054	0.20594
510	0.0092899	0.503	0.15445
515	0.029278	0.60811	0.10918
520	0.063791	0.71	0.076585
525	0.11081	0.7951	0.056227
530	0.16692	0.862	0.041366
535	0.22768	0.91505	0.029353
540	0.29269	0.954	0.020042
545	0.36225	0.98004	0.013312
550	0.43635	0.99495	0.0087823
555	0.51513	1.0001	0.0058573
560	0.59748	0.995	0.0040493
565	0.68121	0.97875	0.0029217
570	0.76425	0.952	0.0022771
575	0.84394	0.91558	0.0019706
580	0.91635	0.87	0.0018066
585	0.97703	0.81623	0.0015449
590	1.023	0.757	0.0012348
595	1.0513	0.69483	0.0011177

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600	1.055	0.631	0.00090564
605	1.0362	0.56654	0.00069467
610	0.99239	0.503	0.00042885
615	0.92861	0.44172	0.00031817
620	0.84346	0.381	0.00025598
625	0.73983	0.32052	0.00015679
630	0.63289	0.265	0.000097694
635	0.53351	0.21702	0.000068944
640	0.44062	0.175	0.000051165
645	0.35453	0.13812	0.000036016
650	0.27862	0.107	0.000024238
655	0.21485	0.081652	0.000016915
660	0.16161	0.061	0.000011906
665	0.1182	0.044327	0.0000081489
670	0.085753	0.032	0.0000056006
675	0.063077	0.023454	0.0000039544
680	0.045834	0.017	0.0000027912
685	0.032057	0.011872	0.0000019176
690	0.022187	0.00821	0.0000013135
695	0.015612	0.0057723	0.00000091519
700	0.011098	0.004102	0.00000064767
705	0.0079233	0.0029291	0.00000046352
710	0.0056531	0.002091	0.00000033304
715	0.0040039	0.0014822	0.00000023823
720	0.0028253	0.001047	0.00000017026
725	0.0019947	0.00074015	0.00000012207
730	0.0013994	0.00052	0.000000087107
735	0.0009698	0.00036093	0.000000061455
740	0.00066847	0.0002492	0.000000043162
745	0.00046141	0.00017231	0.000000030379
750	0.00032073	0.00012	0.000000021554
755	0.00022573	0.00008462	0.000000015493
760	0.00015973	0.00006	0.000000011204
765	0.00011275	0.000042446	0.0000000080873
770	0.000079513	0.00003	0.000000005834
775	0.000056087	0.00002121	0.000000004211
780	0.000039541	0.000014989	0.0000000030383
785	0.000027852	0.000010584	0.0000000021907
790	0.000019597	0.0000074656	0.0000000015778
795	0.00001377	0.0000052592	0.0000000011348
800	0.00000967	0.0000037028	0.00000000081565
805	0.0000067918	0.0000026076	0.00000000058626
810	0.0000047706	0.0000018365	0.00000000042138
815	0.000003355	0.000001295	0.00000000030319
820	0.0000023534	0.00000091092	0.00000000021753
825	0.0000016377	0.00000063564	0.00000000015476

$$\overline{x(\lambda)} = .412453\overline{r(\lambda)} + .357580\overline{g(\lambda)} + .180423\overline{b(\lambda)}$$

$$\overline{y(\lambda)} = .212671\overline{r(\lambda)} + .715160\overline{g(\lambda)} + .072169\overline{b(\lambda)}$$

$$\overline{z(\lambda)} = .019334\overline{r(\lambda)} + .119193\overline{g(\lambda)} + .950227\overline{b(\lambda)}$$

A color is represented by a vector whose trichromatic coordinates X, Y, Z are:

$$X = K_m \int L_e(\lambda).\overline{x(\lambda)}.d\lambda$$
$$Y = K_m \int L_e(\lambda).\overline{y(\lambda)}.d\lambda$$
$$Z = K_m \int L_e(\lambda).\overline{z(\lambda)}.d\lambda$$

from which one can define the trichromatic coordinates x, y, z such as :

$$x = \frac{X}{X+Y+Z}$$
$$y = \frac{Y}{X+Y+Z}$$
$$z = \frac{Z}{X+Y+Z}$$

Since $x+y+z=1$, colors are represented in a plane (xy) whose axes x and y form right angles. Monochromatic colors ($\lambda \in [380\text{nm};780\text{nm}]$) which have coordinates given by

$$x = \frac{\overline{x}(\lambda)}{\overline{x}(\lambda)+\overline{y}(\lambda)+\overline{z}(\lambda)}$$
$$y = \frac{\overline{y}(\lambda)}{\overline{x}(\lambda)+\overline{y}(\lambda)+\overline{z}(\lambda)}$$
$$z = \frac{\overline{z}(\lambda)}{\overline{x}(\lambda)+\overline{y}(\lambda)+\overline{z}(\lambda)}$$

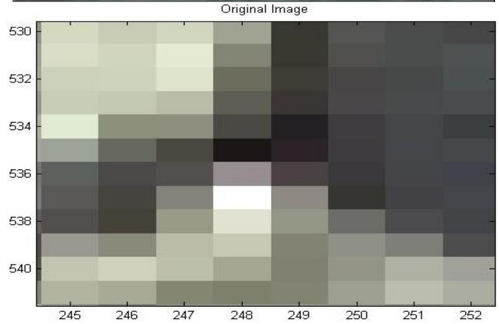
lie along the spectrum locus. As for the RGB system, the surface inside which one may find all real physical colors is delimited by the spectrum locus and by the purple line. This surface is embedded within a circumscribing triangle whose corners X, Y, Z represent the three primaries.

5.3 Experimental Results

Results of four different images shown below by using MATLAB to read image and to extract the color palette. First it converts to tristimulus based on the given tricolor matrix and number of color palette used, also generates a chromaticity diagram indicating the tristimulus variation of the color image.

The variation in the distribution of the tristimulus of the color image can be observed for different tricolor combination and based on number color palette used.

Original Image



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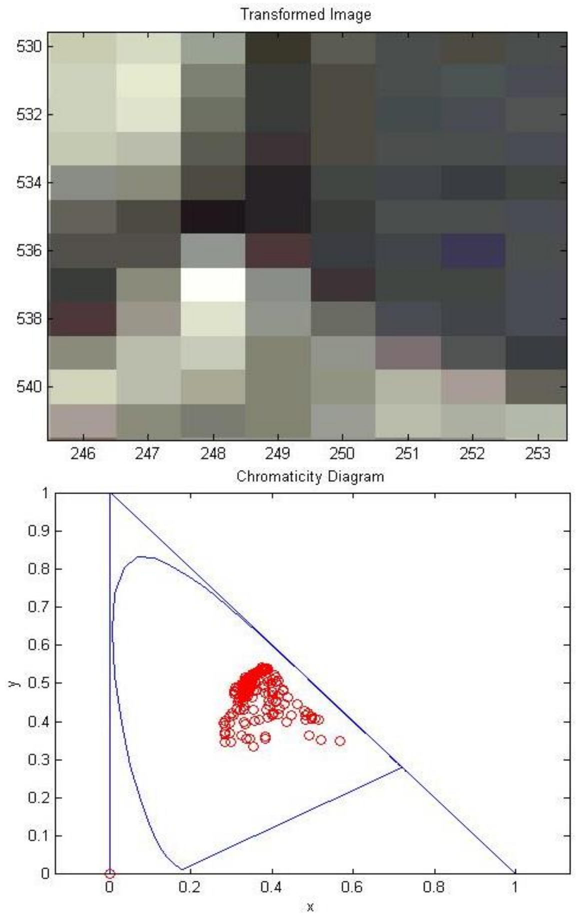


Figure5: Tristimulus Variations and the Chromaticity Diagram for the sampled day Image.

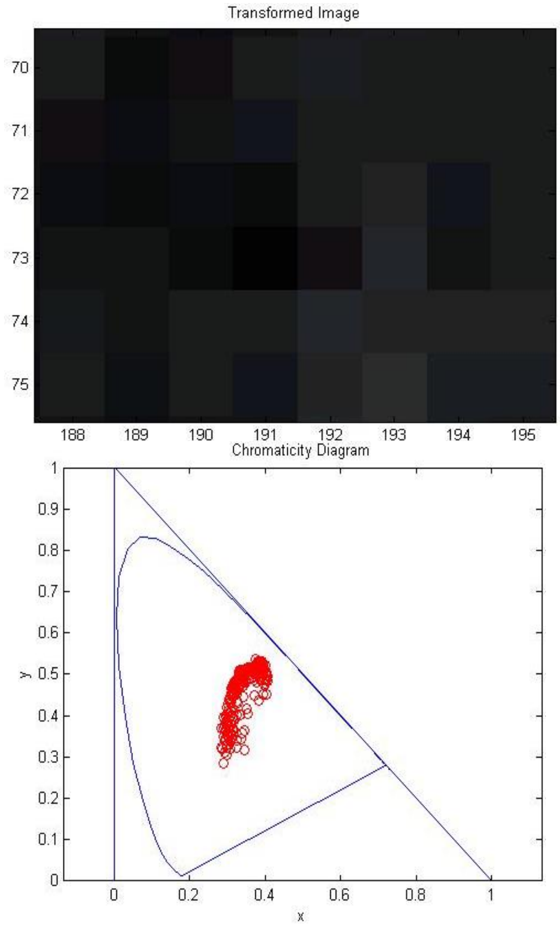
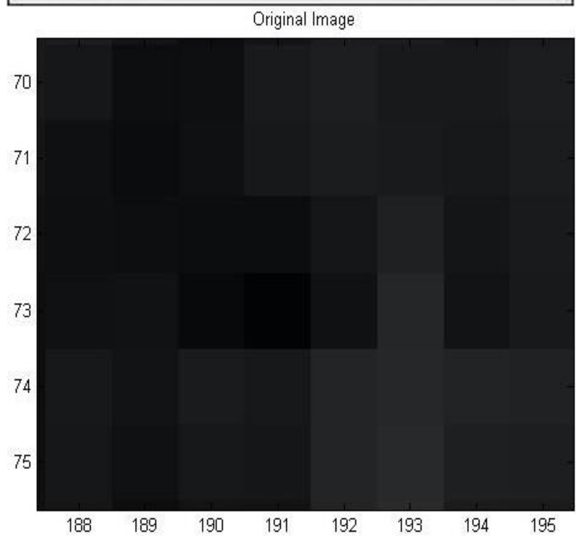
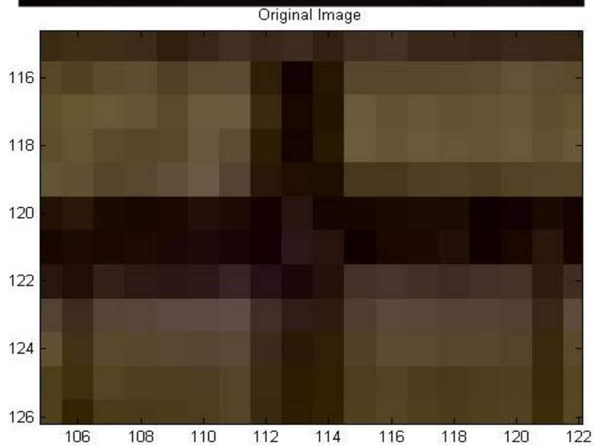


Figure6: Tristimulus Variations and the Chromaticity Diagram for the sampled Shadow Image.





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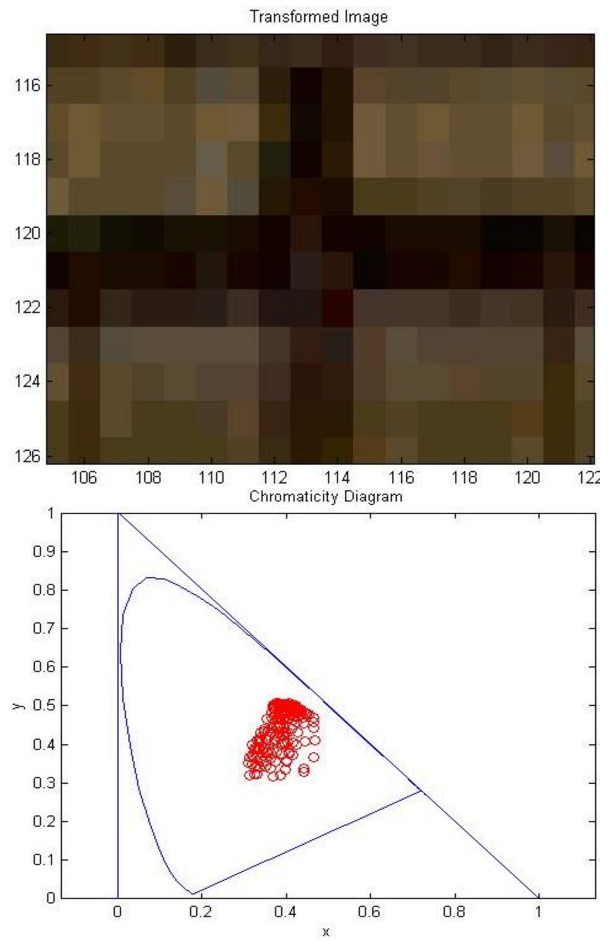
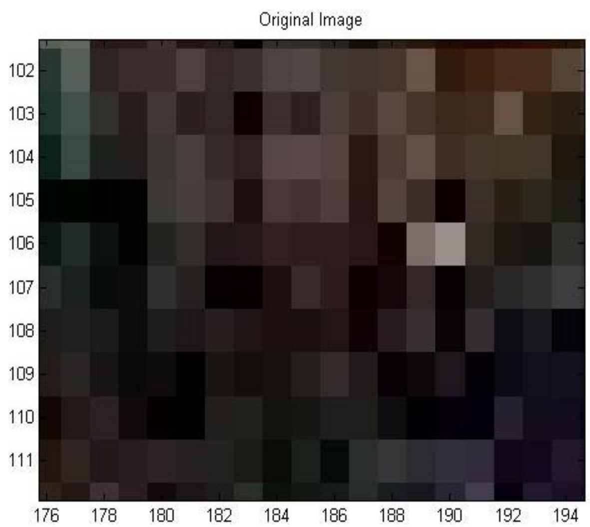


Figure7: Tristimulus Variations and the Chromaticity Diagram for the sampled Night Image.



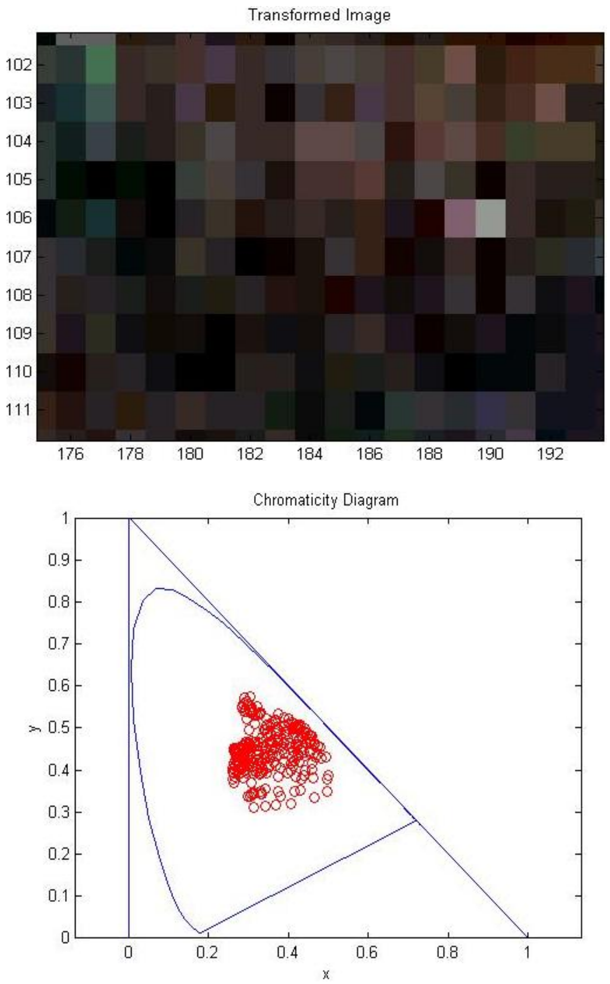


Figure8: Tristimulus Variations and the Chromaticity Diagram for the sampled Night Image with lights.

VI. CONCLUSIONS

Colorimetry, the numerical specification of the color of visual stimuli, is related to the spectral sensitivities of the three cone photoreceptors. Colorimetry is more intuitive when defined in terms of cone excitations than when defined in terms of imaginary primaries, such as the CIE XYZ primaries. Color-matching data and CMFs tell us which spectral distributions will match under a given set of viewing conditions for a given observer. However, they tell us little about the actual color appearance of the match, which can vary enormously with the viewing conditions.

The proposed algorithm does not depend on the acquiring device and takes into account both chromaticity and intensity information in order to carefully estimate the scene illuminant. It has been quantitatively evaluated and outperforms the classical gray world algorithm. As a future research we plan to improve the multi domain analysis that drives the automatic white balancing, considering more features, related to objects whose reflectance's have the most perceptual impact on the human visual system, such as skin, vegetation or sky. We also intend to introduce the influence of the device in the illuminant estimation, investigating the role of the sensor profiling.

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AUTHOR PROFILE

Merugu Suresh, Research Scholar, Department of Civil Engineering, Indian Institute of Technology (IIT) Roorkee, Uttarakhand, India. He received his Master of Science (Electronics and Computers) degree from Jawaharlal Nehru Technological University, Hyderabad in 2003 and M.Tech degree from Jawaharlal Nehru Technological University, Hyderabad in 2009.

Dr. Kamal Jain, Professor, Department of Civil Engineering, Indian Institute of Technology (IIT) Roorkee, Uttarakhand, India. He received his Master of Engineering and PhD from Indian Institute of Technology (IIT) Roorkee. His research and teaching interest include advanced applications of DIP, GPS, Digital Photogrammetry, Remote Sensing and GIS. He is having 20 years experience in above fields and he is active member for many National and International Societies.

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