CHAPTER 3

COLOR MEASUREMENT USING CHROMATICITY DIAGRAM - SOFTWARE

3.1 PREAMBLE

Software has been developed following the CIE 1931 standard of Chromaticity Coordinates to convert the RGB data into its equivalent dominant wavelength and purity. The Luminance or brightness equivalent of such RGB data is also displayed in this software. This chapter contains the User Requirements, Design specifications and Validation details for the Software.

An application needs to be created to analyze the chromaticity information of an RGB image or an RGB data. It should have options to browse to specify the image file to analyze and it should provide an interactive user interface to verify the color information of that image in various color spaces listed below by performing necessary transformation.

- CIE 1931 Color space (x, y and z)
- CIE 1960 Color space (u and v)
- CIE 1976 Color space (u’ and v’)
- Maxwell’s Triangle (Normalized X, Y and Z)

The application should provide the equivalent wavelength, purity and brightness information for an RGB color input using the transformation
specified in section 3.1.1 below. The input RGB color can be specified either from mouse position on the image loaded or it may be fed manually as well. Similarly, for the RGB color chosen, it should display the equivalent coordinates in any of the chromaticity spaces listed above. Also, the application should be able to perform the reverse transformation as well, that is, for a given point in the desired color space, the values of that color in RGB model should be displayed. A marker to specify the point in the Chromaticity Coordinate on the target color space may also be indicated on the screen.

3.1.1 Transformation Calculation: Chromaticity Triangle and Phosphor Triangle

The physical perception of color is based upon three color pigments in the retina. The description of color on the basis of Chromaticity Coordinates not only permits an analysis of color but provides a synthesis technique as well. Using a mixture of two color sources, it is possible to generate any of the colors along the line connecting their respective Chromaticity Coordinates. Since we cannot have a negative number of photons, this means the mixing coefficients must be positive. Using three color sources such as the red, green, and blue phosphors on CRT monitors leads to the set of colors defined by the interior of the "phosphor triangle" shown in Figure 3.1. The formulae for converting from the tristimulus values \((X,Y,Z)\) to the well-known CRT colors \((R,G,B)\) and back, in the software are based on the equations from (2.1) to (2.11).

As long as the position of a desired color \((X,Y,Z)\) is inside the phosphor triangle in Figure 3.1, the values of \(R\), \(G\), and \(B\) will be positive and can therefore be used to drive a CRT monitor.
Figure 3.1 Chromaticity diagram containing the CIE chromaticity triangle associated with pure spectral colors and the triangle associated with CRT phosphors

3.2 SOFTWARE DESIGN

Design of software “Color measurement using Chromaticity Diagram” has been carried out as detailed below:

3.2.1 Software Description

This software consists of an executable file, namely ‘Color measurement’. This utility provides the equivalent wavelength, purity and brightness for either the selected RGB color input from the image or the RGB data fed into it. It also shows the coordinates of that color in the chromaticity spaces such as

- CIE 1931 Color space (x, y and z)
- CIE 1960 Color space (u and v)
- CIE 1976 Color space (u’ and v’), and
- Maxwell’s Triangle (Normalized X, Y and Z)
The position of the Chromaticity Coordinate on the corresponding color space is also indicated on the screen. Similarly, for a given point in the desired color space, the values of that color in RGB model is also displayed.

### 3.2.2 User Interface and Functionality Design

The Visual basic project ‘Color measurement.vbp’ contains three forms such as Chromaticity.frm, GetColor.frm and Get Coordinates.frm and two modules such as Conversion.bas and Display.bas as shown in the Project Explorer window of Figure 3.2.

![Project explorer window of color measurement.vbp](image)

**Figure 3.2 Project explorer window of color measurement.vbp**

#### 3.2.2.1 Chromaticity.frm form

This form provides the main User Interface. User can open any kind of picture file by clicking “Load Picture” button. The loaded picture will be displayed in the left hand side part of the screen. By navigating the mouse on the loaded image, the RGB values of the corresponding pixel is depicted in the display. By clicking on a particular pixel, its equivalent wavelength, purity
and luminance (brightness) are shown. The user can select the desired color space and the chosen pixel’s coordinates in the selected color space is displayed. By default, the software selects the CIE 1931 color space only. A sample output of Color measurement using Chromaticity Diagram is shown in Figure 3.3.

![Figure 3.3 Sample output of color measurement using chromaticity diagram](image)

### 3.2.2.2 *GetColor.frm form*

This form is launched when the user clicks the **Check for Color** command button in Chromaticity.frm screen. It prompts the user to enter Red, Green and Blue values between 0 and 255. Its equivalent wavelength, purity and luminance are displayed on the screen.
3.2.2.3  \textit{GetCoordinates.frm} form

This form is loaded when the user clicks the \textit{Find Color} command button in the main screen. It prompts the user to enter the x and y coordinates values of the target color space. Its equivalent wavelength, purity and luminance are displayed on the screen. We can also see the equivalent RGB data for that (x, y) coordinate. The fact of inefficiency of the CRT display in displaying the negative valued RGB data can be verified here. For example, when x=0.1 and y=0.5, the RGB values are R=-135, G=255 and B=145. This point goes out of the Phosphor-triangle; however its equivalent wavelength, purity and luminance can be seen as shown in the Figure 3.4.

![Sample output for GetCoordinates.frm](image)

\textit{Figure 3.4 Sample output for GetCoordinates.frm}
3.2.2.4  Conversion.bas module

This is the main module that contains functions for conversion between different color spaces for given coordinate values. It also contains type and definitions for color systems and initializing procedures. It also converts x and y CIE Chromaticity Coordinates into its equivalent wavelength, purity and luminance. It also mutually converts the color coordinates of various color spaces such as CIE 1931, CIE 1960, CIE 1976 and Maxwell’s triangle.

3.2.2.5  Display.bas module

This module contains the public function display() which takes the RGB values as input and displays different chromaticity measurements in the main form Chromaticity.frm.

3.2.3  Implementation

The set of common and core implementations include Color System type definition with set of functions and procedures. A color system is defined by the CIE x and y coordinates of its three primary illuminants and the x and y coordinates of the white point.

3.2.3.1  Type definition

A Color system is defined by the CIE x and y coordinates of its three primary illuminants and the x and y coordinates of the white point. The primary illuminants are Red (700 nm) with Chromaticity Coordinates \( x_r=0.7350, \ y_r=0.2650, \) Green (545 nm) with Chromaticity Coordinates \( x_g=0.2740, \ y_g=0.7170, \) and Blue (400 nm) with Chromaticity Coordinates \( x_b=0.1670, \ y_b=0.0090. \) The Coordinates for the reference illuminant White is \( x_w=0.3333, \ y_w=0.3333. \)
3.2.3.2 Calculation of brightness

The public function Brightness() calculates the luminance value of the given Red, Green and Blue values as per the equation (2.4). This function has been written as follows in the Software.

```vbnet
Public Function brightness(ByVal r As Double, ByVal g As Double, ByVal b As Double) As Double
    Dim greatest As Integer
    greatest = 255
    brightness = ((100#/greatest) * (0.299 * r + 0.587 * g + 0.114*b))
End Function
```

3.2.3.3 Conversion of x and y coordinate to its equivalent wavelength and purity

The xyz_to_wp() function finds the wavelength and purity for the given x and y Chromaticity Coordinates of CIE 1931 Chromaticity Diagram. This uses the geometry of the RGB triangle and CIE color space to find dominant wavelength. From the white point of the color space, a virtual line is drawn to the color specified by the XYZ coordinates. This line is extended until it reaches the Color space contour. The wavelength specified by the color space at the point of intersection of this line in the color space outer curve gives the dominant wavelength. Similarly the purity is calculated as the percentage of proximity of the color point specified by XYZ coordinates to the outer contour of the CIE Color space in the virtual line. This process of conversion of x and y Chromaticity Coordinate to its equivalent wavelength and purity is schematically shown in Figure 3.5.
Figure 3.5  Flow chart of conversion of (x, y) coordinate to its equivalent wavelength and purity
The complete software for this function has been given in Appendix 3.

3.2.3.4 Conversion of RGB data to x, y and z chromaticity coordinates

For a given RGB data, its equivalent x, y and z coordinates in CIE 1931 Color space is displayed from this function. The following preliminary requirements are in this function:

- R, G and B are between the range 0 and 255
- If all RGB values are positive, then they fall into the phosphor triangle
- x and y are calculated using the equations from (2.1) to (2.9)
- Equal energy White with x=y=z=1/3 is adopted
- z is derived trivially as 1-(x+y)
- Color system is CIE 1931 Color space

The software for this function has been completely given in Appendix 3.

3.2.3.5 Conversion of x, y and z chromaticity coordinates to RGB data

For a given x, y and z coordinates in CIE 1931 Color space, its equivalent RGB data is displayed from this function. The following preliminary requirements are in this function:

- x, y and z are between the range 0 and 1
- If all RGB values are not positive for some values of x and y, then the (x,y) coordinate may fall out of the phosphor triangle. However, its equivalent Wavelength, purity and Brightness will be displayed.
This function uses the inverse of transformation specified in the Section 3.2.3.4. The software for this function has also been completely given in Appendix 3.

### 3.3 TESTING

Testing of Software includes giving various inputs to the Software and studying the output.

![Figure 3.6 RGB data to wavelength and purity conversion](image)

- An image is loaded in to the picture box by clicking on load picture… command button. By moving the mouse on the image loaded, the RGB content of the corresponding pixel is displayed. When the mouse button is clicked on any pixel, the pixel’s equivalent RGB data, wavelength, purity and luminance are displayed as shown in Figure 3.6.
• Similar testing can be run for the *Check for a Color*… command button. Using this button, any RGB data can be fed into the software. After feeding the RGB data, if *Ok* button is clicked, the RGB data’s equivalent x and y coordinates, wavelength, purity and luminance are displayed as shown in Figure 3.7.

![Figure 3.7 RGB to xyz conversion](image)

• *Find Color*… command button can be tested by clicking on and feeding the x and y Chromaticity Coordinates. Equivalent RGB data, wavelength, purity and Luminance are displayed on the screen as shown in Figure 3.8.
3.4 APPLICATION OF SOFTWARE

This ‘Color measurement using Chromaticity Diagram’ software has been utilized in this thesis for two purposes. First by capturing image of the assay and getting RGB data from the pixel of the image, calculation of the concentration of glucose from the purity of the color has been done. Next, with the help of RGB color sensor, RGB equivalent of the color of the assay is directly obtained. From this RGB data, purity of the color of the assay has been obtained in this software and measurement of concentration of glucose has been done.

This Software is a general purpose software. Wherever a color’s wavelength and its spectral purity are needed, this software can be used.