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Development of computer controlled colour mixing illumination network using RGB LEDs

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Abstract: - *At present LED light sources are gradually applied to LCD backlighting and video projection. But increasing luminous efficacy (lm/W) makes the use of LED light sources for general lighting and modern lighting like mood lighting. Based on the demands of mood lighting and combination of light colour of Red, Green and Blue LED light sources gives the desired colour effect. This paper is focused on the concept of colour mixing. For this an attempt is made to design personal computer based RGB illumination module. It consist of microcontroller and LED driver ,will enable the users to select desired colour by just clicking on the CIE chromaticity chart. The microcontroller regulates LED light output with pulse width modulated current and changes the light colour with the ratios of red, green and blue LEDs. This paper covers the block diagram development necessary for this RGB illumination module.*

Index Terms: - *RGB LEDs, CIE chromaticity chart, illumination network, PWM, tristimulus values*

1. INTRODUCTION

From the literature survey it is observed that Light Emitting Diodes (LEDs) are widely used in special lighting areas like e.g. traffic lights, signaling, signage and outstanding architectural implementations but these are niche applications compared with general illumination.[1].There is strong interest in using LEDs for general illumination and modern lighting like mood lighting due to the potential they offer for energy saving, environmental friendliness, long life.

General illumination requires primarily white light located in the centre of the chromaticity diagram. There are two ways for making white light using LEDs either colour mixing or using phosphors for down converting the light of Ultraviolet or blue LEDs.[2]

Colour mixing enables colour adjustability which is considered to be a most attractive feature of future

LED lamps. Since colour changes moods, it is known the atmosphere of a room can be changed if we change the colour of lighting. Mixing the light of red ,green and blue LEDs ,any colour can be created inside the colour triangle defined by the chromaticity colour space diagram[2].The target colour can be achieved by varying the lumen (brightness) output of each LED as to allow gradual change of colours. The brightness of each LED is controlled by configuring PWM through logic circuit. The logic circuit contains the programming and setting of constant current sinks is used to vary the duty factor of the d.c.current to control the brightness of the LED.A graphical user interface (GUI)will allow user to choose the desired colour to be displayed by using LEDs array[3],[4].

The concept of colour and colour mixing are discussed in II. CIE chromaticity Diagram and Pulse Width modulation is explained in

III. Methodology for design the computer controlled illumination network using RGB LEDs is explained in IV.

I) CONCEPT OF COLOUR AND COLOUR MIXING

A) Concept of Colour

Colour is made up of hue, saturation and brightness or Luminance (HSL).HSL is a three dimensional co-ordinate system shown in Fig.2.1 is useful for describing a colour mathematically. In this mode, in which the three values describes by cone .Hue is represented by an angular position on the circle. Pure colours red, green, cyan, yellow, blue and magenta describes the hue of colours.

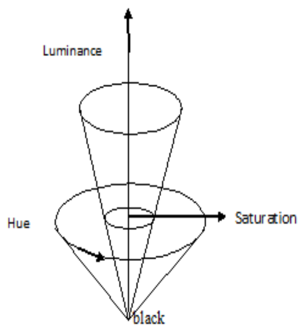

Fig 2.1 Representation of colour

Saturation ranges from 0 to 1 and is represented by the radius of the hue circle or cone. A value 0 indicates gray and 1 indicates pure primary colour.

Luminance is represented by vertical height of the cone. It reduces the value of the primary colours while keeping the same ratio.

B) Concept of Colour mixing

There are two approaches for colour mixing.Additive colour mixing and Substractive colour mixing.The primaries for additive colour mixing are red, green and blue (RGB) .The primaries for subtractive colour mixing are cyan, magenta and yellow. Generally ,subtractive colour mixing is used in paints and pigments. Additive colour mixing is used for light sources. For additive colour mixing, independent red, green and blue are regarded as perpendicular three unit vectors and form a colour space. In three dimension space equal energy white is composed of the red, green and blue unit vectors.

$$\vec{W} = \vec{R} + \vec{G} + \vec{B} \quad (1)$$

Since human eyes have different sensitivities for red, green and blue, the unit values of the unit vectors $\vec{R}, \vec{G}, \vec{B}$ are therefore not equal to each other. Depending on different wavelength of red, green and blue different combinations that may produce white.

Accordingly general colour can be produced ,it is given as following :

$$\vec{C} = R\vec{R} + G\vec{G} + B\vec{B} \quad (2)$$

Where R,G and B are magnitudes of vectors $\vec{R}, \vec{G}, \vec{B}$

In the spectrum of visible light ,each wavelength emits a pure colour and referred to as spectral colour. Hence ,spectral colour with wavelength ‘ λ’ written as

$$\vec{C}(\lambda) = r(\lambda)\vec{R} + g(\lambda)\vec{G} + b(\lambda)\vec{B}$$
(3)

Where $r(\lambda), g(\lambda), b(\lambda)$ respectively corresponds to magnitudes of red, green and blue.

II) CIE CHROMATICITY DIAGRAM AND PULSE WIDTH MODULATION

A) CIE chromaticity diagram

The selection of the desired colour by the user is based on a colour space diagram known as 1931 CIE xyz standard chromaticity chart .The chart is shown in Fig.3.1. It shows horse shoe shaped colour chart that displays the colours perceptible to human eyes regardless of its brightness or its lighting level. The ticks and numbers by the side of the curve denote the wavelength of pure colours in the unit of micron. Any colour inside the curve can be produced by the combination of two or more of the primary colours,in this case red, green and blue. In CIE 1931 chromaticity chart of Fig.3.1.it is observed that there is a triangle drawn in black .This triangle shows borderline named colour garnut of the colours that the LED array will be able to produce by combining two or more of primary colours.The definition of colour garnut is the entire range of observable colour that may be obtained due to limitation caused by the constraints in the red ,green and blue LED used.

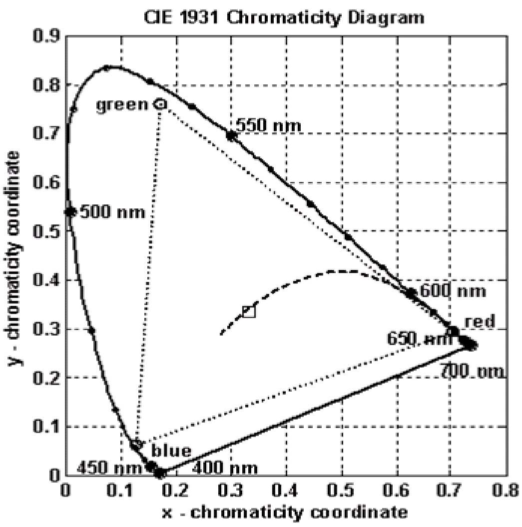

Fig 3.1 CIE Chromaticity Chart

CIE has devised a new colour space which is based on the tristimulus values XYZ. Also it should be noted that the tristimulus values XYZ in(uppercase) are not the same as the chromaticity co-ordinates xyz in (lowercase).The x-axis of the chart represent the x value while y- axis represent y value of the xyz colour space co-ordinates, when the mouse float over the chart ,it will produce the corresponding x and y values. Subsequently the x and y values are converted to RGB values to be sent to the microcontroller.

The equations involved for the conversion from xyz color space to tristimulus values XYZ are shown as follows:

The equations involved for the conversion from xyz color space to tristimulus values XYZ are shown as follows:

$$X_i = \frac{X_i}{y_i} Y_i \quad (4)$$

$$Y_i = Y_i$$
(5)

$$Z_i = \frac{1-X_i - Z_i}{Y_i} Y_i$$
(6)

Since a color is composed of red, green and blue primaries, the stimulus values of any colour ‘C’ are respectively equal to the sum of the corresponding red, green and blue stimulus values.

$$X_c = X_r + X_g + X_b$$
(7)

$$Y_c = Y_r + Y_g + Y_b$$
(8)

$$Z_c = Z_r + Z_g + Z_b \quad (9)$$

Then rewriting equations (4) to (8) in the form of matrix

$$\begin{bmatrix} X_c \\ Y_c \\ Z_c \end{bmatrix} = \begin{bmatrix} \frac{x_r}{y_r} & \frac{x_g}{y_g} & \frac{x_b}{y_b} \\ 1 & 1 & 1 \\ \frac{1-x_r-y_r}{y_r} & \frac{1-x_g-y_g}{y_g} & \frac{1-x_b-y_b}{y_b} \end{bmatrix} \begin{bmatrix} Y_r \\ Y_g \\ Y_b \end{bmatrix} \quad (10)$$

Then the required luminance vector for red, green and blue LED is

$$\begin{bmatrix} Y_r \\ Y_g \\ Y_b \end{bmatrix} = \begin{bmatrix} \frac{x_r}{y_r} & \frac{x_g}{y_g} & \frac{x_b}{y_b} \\ 1 & 1 & 1 \\ \frac{1-x_r-y_r}{y_r} & \frac{1-x_g-y_g}{y_g} & \frac{1-x_b-y_b}{y_b} \end{bmatrix}^{-1} \begin{bmatrix} X_c \\ Y_c \\ Z_c \end{bmatrix} \quad (11)$$

As the luminance Y_c is one lumen the required luminance for red ,green and blue LEDs are

$$\begin{bmatrix} Y_r \\ Y_g \\ Y_b \end{bmatrix} = \begin{bmatrix} \frac{x_r}{y_r} & \frac{x_g}{y_g} & \frac{x_b}{y_b} \\ 1 & 1 & 1 \\ \frac{1-x_r-y_r}{y_r} & \frac{1-x_g-y_g}{y_g} & \frac{1-x_b-y_b}{y_b} \end{bmatrix}^{-1} \begin{bmatrix} \frac{x_c}{y_c} \\ 1 \\ \frac{1-x_c-y_c}{y_c} \end{bmatrix} \quad (12)$$

Where the coordinates $x_c = \frac{X_c}{X_c + Y_c + Z_c}$, $y_c = \frac{Y_c}{X_c + Y_c + Z_c}$

B) Pulse Width Modulation

Pulse Width Modulation (PWM) is the modulation technique used in this study because PWM is powerful technique for controlling analog circuits with a microprocessor's digital outputs.PWM is employed in a wide variety of applications ,ranging from measurement and communications to power control and convertion.PWM can control analog circuits digitally ,therefore system costs and power consumption can be drastically reduced .Through the use of high resolution counters ,the duty cycle of square wave is modulated to encode a specific analog signal level, The PWM signal is still digital because at any given instant of time ,the fully DC supply is either fully ON or fully OFF .The voltage or current source is supplied to the analog load by means of a repeating series of ON and OFF pulses .The ON time is the time during which the DC supply is applied to the load and the OFF time is the period during which the supply is switched OFF. Given a sufficient bandwidth, any analog value can be encoded with PWM.In this study ,LED is the analog load that needs a set of specified current values in analog form to produce different brightness.

III) METHDOLOGY

Methodology for design the computer controlled multicolour illumination network using RGB based Light Emitting Diodes is divided into two sections .

- Hardware Design
- Software Design

Hardware design consist of microcontroller circuit and serial communication and software design include Graphical User Interface by using Visual Basic and the programme of the microcontroller by using MPLABIDE.

A) Hardware design

Fig. 4.1. Shows the block diagram for computer controlled illumination Network using RGB based Light Emitting Diodes. It consists of PIC16F877A microcontroller, LED driver (ULN 2803) ,MAX RS 232 driver ,RGB LEDs,LM135 Temperature Sensor

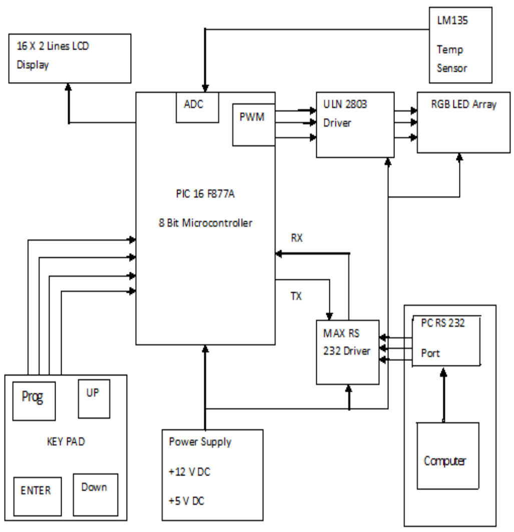

Fig 4.1 Block Diagram of Computer Controlled Illumination Module

PIC16F877A is chosen because it is a powerful IC and cheaper than other microcontrollers available in the market. This microcontroller will generate duty cycles by using Pulse Width Modulation (PWM) according to the RGB values (LEDs brightness) that are sent through the serial cable from the computer. The duty cycles produced are then sent to LED driver and it will always be regenerating corresponding duty cycles whenever there are any new RGB values received.

The pulse signal will be realized by controlling the output Enable of the Red, Green and Blue LED drivers. At first, shift registers of all LED drivers have filled with Logic '1' and then the latch Enable pin is enabled to send the data to latch the data. Thus, every output pin of LED driver is activated and each of it sinks a certain current. Subsequently, the LED will be lighted up in different brightness according to its duty cycle.

To communicate between GUI and microcontroller to control duty cycle, serial communication is used. The conversion from the serial data transmission to parallel is done using a Universal Asynchronous Receiver Transmitter (UART). In this system the interfacing with the PIC16F877A microcontroller is achieved through RS232 protocol. As temperature affect on output colour temperature compensation circuit is also provided.

B) Software design

Software design mainly deals with the building of the GUI of CIE 1931 Chromaticity Chart using Visual basic 6.0.The x-y 1931 chromaticity coordinates are calculated by bringing into play the height and width of the chart When the mouse pointer floats over the CIE chart the program will dynamically calculate the RGB values from the x and y coordinates of the chart using transformation equations (4) to (12).

In the event of left button mouse click when the mouse pointer is within the region of the colour garnut, then program will send the RGB values through serial port to the microcontroller. Then microcontroller will number the RGB values to produce the corresponding duty cycle of PWM. After receiving RGB values from computer, PIC microcontroller programming design the generating colour outputs as specified by the user from the GUI.

IV) CONCLUSION

A block diagram is designed for a computer controlled illumination Network using RGB based Light Emitting Diodes with 8 bit microcontroller in this study. Concept of additive colour mixing can be efficiently used to produce different colours inside the colour garnut of chromaticity chart by using visual basic and PWM of current for controlling brightness of LEDs. Effect of temperature on output colour is compensated by using

Feed forward compensation circuit. This concept can be used in various mood lighting applications such as parks, hotels and restaurants.

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