Temperature Controlling System for LED lighting Based on ARM

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***Abstract*—Since LEDs are generally considered to be an important lighting source of the future, an ARM-based LED intelligent lighting system was provided in this paper. According to the ambient temperature obtained by sensors, the designed system can adjust the glow color automatically to provide a pleasant lighting environment. Based on the ARM Cortex-M0 processor, the hardware and software of this system were accomplished and a series of pulse width modulation signals were generated to drive the LEDs. The testing results of the physical prototype show that the designed system works well. Thus, the preliminary research proves the possibilities of smart lighting.**

Keywords—smart LED; ARM Cortex-M0; PWM; lighting

I. Introduction

With the improvement of the people's living standard, lighting is very promising not only for its simple function to light a space and provide a fixed color of light, but also for its adjustment of mood. In different weather or places, lighting can create different types of atmosphere to meet people's requirement in psychology [1-2]. For example, in scorching summer, cold colors including blue and purple bring freshness to your eyes; while in the freezing winter, you had better choose warm color such as red, yellow and orange. In regard to this, an intelligent temperature controlled lighting system was designed in this paper, which can be applied to landscape lighting, interior lighting, backlighting and automotive interior lighting and other occasions. The provided system can adjust the color of lighting automatically according to ambient temperature, so that people in different circumstances obtain a more comfortable lighting experience.

Currently, fluorescent lamps represent the most popular lighting solution [3]. However, because of their Lighting color monotony, high energy consumption and limited programmability, fluorescent lamps cannot meet requirements of many modern applications. Unlike fluorescent lamps, LED (light emitting diode) has capability to generate instantly different colors and intensities. The light color covers almost saturated color of CIE (International Commission on Illumination) chromaticity diagram. Compared with other light source, LED has incomparable advantages in mixing light and it will be widely applied in the intelligent lighting system [4].

II. Hardware Design and Implementation

The hardware mainly provides the following functions. Firstly, the sensor module senses the ambient temperature and sends the detected temperature information to the MCU (Micro Controller Unit). Then, MCU receives and processes the temperature information. Finally, MCU controls LCD (Liquid Crystal Display) module to display real-time temperature on the one hand, on the other hand, it outputs driver signals to control the color of LED lighting module.

A. Components of the System

As shown in Fig.1, this system mainly consists of four parts: MCU, sensor module, display module and LED module.

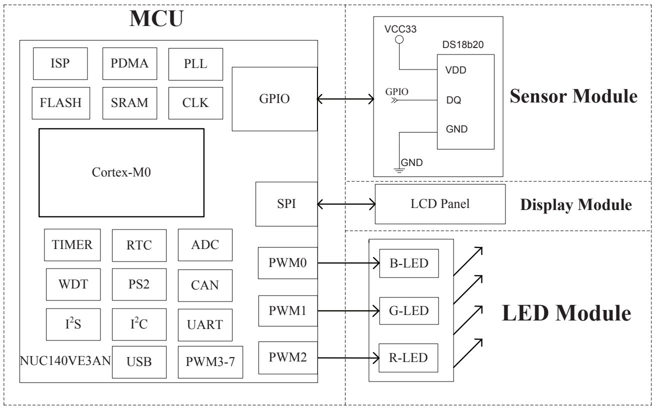

Fig. 1. Hardware block diagram

The main processor used in our system is a Nuvoton's NUC140VE3AN, which is one of the ARM Cortex-M0 core embedded microprocessors for industrial control. The Cortex-M0 is the newest ARM embedded processor with 32-bit performance and runs up to 50MHz, up to 128K-byte embedded flash, and 16K-byte embedded SRAM [5]. It also integrates 8-channel 16-bit PWM generator, 4 groups SPI, GPIO, Timers, Watchdog Timer, RTC, PDMA, UART, I^2C, LIN, CAN, USB, ADC and other plenty peripherals. This processor fully meets the requirements of system and reduces the energy consumption and cost at the same time.

Sensor module adopts American DALLAS Company DS18B20 digital temperature measurement module, it has a unique single-wire interface mode. The communication between DS18b20 and processor can be completed by simply connecting the DS18b20 data port to a GPIO port in this design.

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Display module uses 128 × 64 dot matrix LCD digital display, which has low power consumption, small size, modularity, and many other advantages. In this system, LCD module uses the on-chip SPI interface to communicate with processor.

LED module uses on-chip PWM function to drive red LED, green LED and blue LED for mixing colorful lighting. PWM0, PWM1 and PWM2 drive red LED, green LED and blue LED separately.

B. Implementation of Test Platform

Based on the experimental development board named Nuvoton's Nu-LB-NUC140, a test platform is built as shown in Fig.2. The test platform is connected to a PC running the KEIL IDE (Integrated Development Environment) via USB interface. The temperature sensor is in place. After programming and then pressing the reset button, the system begins to work. As can be seen from Fig.2, the ambient temperature is 19.5 ℃ and the illumination color is yellow.

Fig. 2. Test platform

C. Mixing Principle

The tricolor principle shows that all colors in nature can be made up of three independent primary colors by mixing together in certain proportion. Approaches of color mixing include additive and subtractive color mixings. Generally, subtractive color mixing is used in paints and pigments. The mixing of light sources uses additive color mixing. For additive color mixing, independent red, green and blue are regarded as perpendicular three unit vectors and form a color space. Color is made up of hue, saturation and brightness. PWM (Pulse Width Modulation) dimming technology is based on the human eye vision persistence features. The LED brightness is controlled by adjusting the relative ratios of the on time and off time. The advantage of PWM dimming technology is that the forward current is always constant, so hue of LED does not vary with brightness like it does with analog dimming. In this paper, we controls LED brightness by controlling the PWM duty ratio, its theory is derived as follows： ϕ is luminous flux of LED, ϕ_{ON} is luminous flux of LED turn-on, D_{ON} is duty cycle of PWM, that is

$$\phi = \phi_{ON} \times D_{ON} \tag{1}$$

When LED turns on, it can be equivalent to the resistance. R_{LED} is equivalent resistance of LED, I_{ON} is current of LED turn-on, η is luminous efficiency, we get

$$\phi_{ON} = I_{ON}^2 \times R_{LED} \times \eta \tag{2}$$

When the LED material remains the same, equivalent resistance, current of LED and luminous efficiency are fixed. According to (2), it shows that the ϕ_{ON} is a fixed value. We concluded that luminous flux of LED is proportional to the duty cycle of PWM by the (1). PWM dimming technology uses constant current driver, so that the relative spectral power distribution has not changed, in other words, hue of LED does not change. Ultimately, we come to the conclusion that we can control the light color by varying the duty cycle of PWM.

III. SOFTWARE DESIGN

A. Main Function

This system uses keil MDK-ARM software development environment. The whole program follows a modular design concept. The entire program sets up two functions module subprograms, one is to implement temperature acquisition and the other is for PWM driving. It simplifies the design of the structure. Main function flow diagram is illustrated in Fig.3. Firstly, main function initializes device, calls the subprogram of temperature acquisition and saves temperature data. Then the main function determines the range of surrounding temperature by nested conditional statement. Main function calls data in the array selectively and the array saves duty ratio of PWM. Finally, the main function produces PWM signals according to the data of the array.

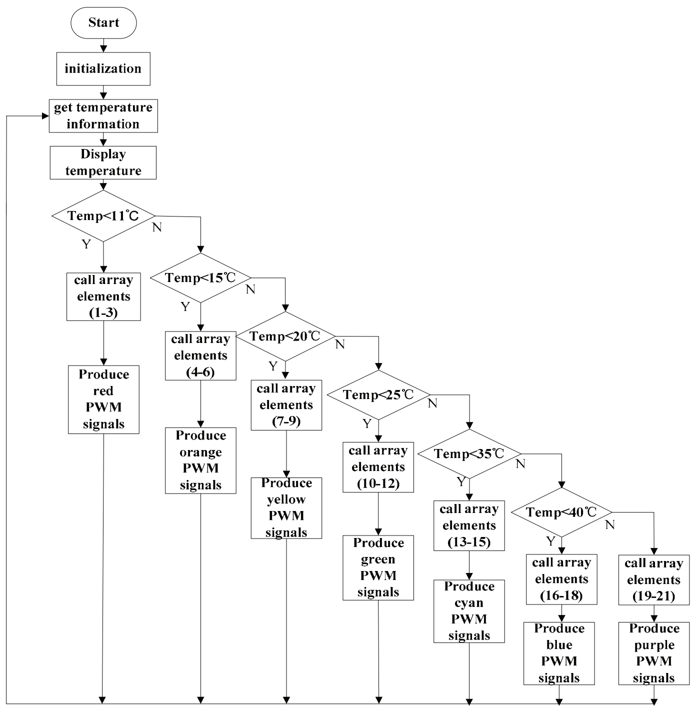


Fig. 3. Main function flow diagram

B. *Color Matching Calculation*

According to the principle of color science, the color of the light is determined by color matching equation. Equation (3) gives a general color production,

$$C=R(R)+G(G)+B(B) \tag{3}$$

Where R, G and B are the ratio of red, green and blue respectively.

In 1931, CIE defined color matching experiment and established a standard of producing color. CIE 1931 chromaticity diagram is illustrated in Fig.4 [6]. X-axis represents the ratio of red; y-axis represents the ratio of green. Since

$$x+y+z=1 \tag{4}$$

A two-dimension x-y plot is sufficient to represent each perceived color.

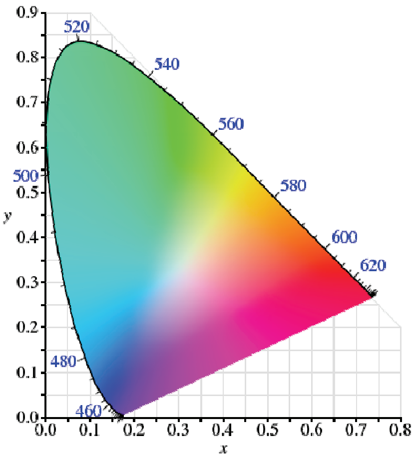


Fig. 4. CIE 1931 chromaticity diagram

Chromaticity coordinates C (x_c, y_c, z_c) which represents a certain color can be obtained easily from *Fig. 4*. X′ (x'_r, y'_r, z'_r), Y′ (x'_g, y'_g, z'_g) and Z′ (x'_b, y'_b, z'_b) represent separately the chromaticity coordinates of adopted RGB-LED. According to the Optical Law, we get

$$\left.\begin{aligned} X' &= x'_r X + y'_r Y + z'_r Z \\ Y' &= x'_g X + y'_g Y + z'_g Z \\ Z' &= x'_b X + y'_b Y + z'_b Z \end{aligned}\right\} \tag{5}$$

In (5), X, Y and Z are the primary colors in CIE chromaticity diagram. The equation expressed in the form of matrix is

$$\begin{Bmatrix} X' \\ Y' \\ Z' \end{Bmatrix} = A \times \begin{Bmatrix} X \\ Y \\ Z \end{Bmatrix} \tag{6}$$

where $A=\begin{bmatrix} x'_r & y'_r & z'_r \\ x'_g & y'_g & z'_g \\ x'_b & y'_b & z'_b \end{bmatrix}$. it is transposed that

$$\begin{Bmatrix} X \\ Y \\ Z \end{Bmatrix} = A^{-1} \times \begin{Bmatrix} X' \\ Y' \\ Z' \end{Bmatrix} \tag{7}$$

Where A^{-1} is the inverse of A matrix. According to the CIE 1931 standard, we find

$$C = [x_c \quad y_c \quad z_c] \times \begin{Bmatrix} X \\ Y \\ Z \end{Bmatrix} \tag{8}$$

In combination with (7) and (8), we get

$$C = [x_c \quad y_c \quad z_c] \times A^{-1} \times \begin{Bmatrix} X' \\ Y' \\ Z' \end{Bmatrix} = [r \quad g \quad b] \times \begin{Bmatrix} X' \\ Y' \\ Z' \end{Bmatrix} \tag{9}$$

Where r, g and b are defined as the brightness ratio of RGB-LED which can be used to mix color C [7]. According to the above Color Matching Calculation, We obtained the color matching ratio table in Table I.

TABLE I. COLOR MATCHING RATIO

Color	Ratio of RGB-LED		
	r	*g*	*b*
Red	100%	0%	0%
Orange	60%	40%	0%
Yellow	50%	50%	0%
Green	0%	100%	0%
Cyan	0%	50%	50%
Blue	0%	0%	100%
Purple	37%	8%	55%

According to the color matching ratio, we implemented the illumination of above color and display the current temperature. Physical display photograph is illustrated in Fig. 5.

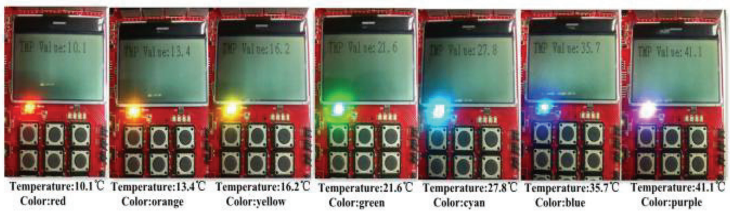


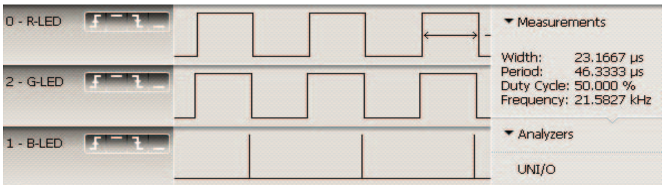
Fig. 5. physical display photograph

C. PWM Signal Generation

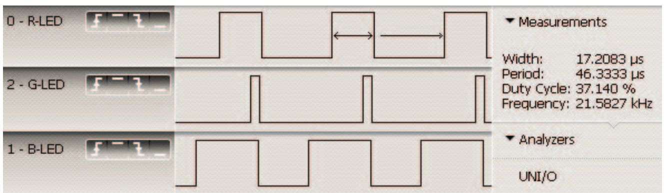
In this processor, PWM have double buffering function the reload value is updated at the start of next period without affecting current timer operation. The double buffering function allows duty ratio written at any point in current cycle. The loaded value will take effect from next cycle. PWM wave generation steps are shown as follows.

- Setup clock source register and prescaler.
- Setup inverter off, auto-reload mode and stop PWM-timer.
- Setup comparator register for setting PWM duty.
- Setup PWM down-counter register for setting PWM period.
- Setup corresponding GPIO pins as PWM function.
- Enable PWM start running.

Fig.6 shows the output signal of PWM generator in mixing light. (a) is wave diagram to produce yellow light and (b) is purple light. According to entered two groups data 0x007f, 0x007f, 0 and 0x005e, 0x0013, 0x008b, the duty cycle of each wave is output as 50%, 50%, 0% and 37%, 8%, 55%, respectively.



(a) mixing yellow light



(b) mixing purple light

Fig. 6. two groups PWM output wave for mixing light

IV. CONCLUSIONS

This paper outlines the principles of tricolor and PWM dimming technology, focusing on the hardware, software, structure, color matching calculation and on-chip PWM module. With the high processing speed of the ARM microprocessor, the LED lighting intelligent temperature control system is constructed with the ARM Cortex-M0 of Nuvoton's NUC140VE3AN.It fully meets the requirements of system and reduces the energy consumption and cost at the same time. This system also adopts the temperature sensor module, making the lighting environment with real-time temperature adjustment, and improves the lighting comfort. After the physical tests, we found that the system has the advantages of temperature measurement accuracy, good luminous effect and short response time and can meet the actual needs.

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