Design and Implementation of an LED Mood Lighting System Using Personalized Color Sequence Generation

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Received December 15, 2011; revised March 2, 2012; revised April 28, 2012; accepted May 16, 2012; published December 27, 2012

Abstract

In this paper, we present a new LED (Light Emitting Diode) mood lighting system interacting with smartphones based on the generation of different light sequences. In the proposed system, one light sequence is considered to be one unit of the service contents, which is then transmitted through a network and played in an LED lighting system. To this end, we propose a novel generation scheme using a smartphone, and a decoding/playing mechanism in an LED lighting system. The lighting sequences have a fixed period divided into predefined time units. Two modes - basic and interpolation – are supported in each time unit when playing a color sequence. In the basic mode, the color is maintained for the entire time unit, whereas in the interpolation mode the color is interpolated. The sequence is decoded and played in the lighting circuit by changing the duty cycle of a PWM (Pulse Width Modulation) signal. A demonstration system of the overall proposed method was using smartphones, a server and an LED lighting system. The results from this experiment show the validity and applicability of the proposed scheme.

Keywords: LED lighting, LED color sequence, Color sequence generation, color sequence playing

This work was supported in part by MEST and DGIST (DGIST Convergence Science Center) and also supported in part by the MKE(The Ministry of Knowledge Economy), Korea, under the ITRC(Information Technology Research Center) support program supervised by the NIPA(National IT Industry Promotion Agency) (NIPA-2012-C1090-1221-0005).

http://dx.doi.org/10.3837/tiis.2012.12.009

1. Introduction

LED lighting systems which have such characteristics as low power, high efficiency and natural color have been widely developed in these days [1]-[10].

Due to the rapid development of LED related technologies, LED applications have expanded considerably [1][2][3][4][5][6][7][8][9][10]. For example, LED applications have been implemented into full color screens, 360 degree color display system [4], digital street lamp [1], lighting systems based on VLC (Visible Light Communications) [6], LED lighting system for facial expression in robot [8] and so on.

Especially, after the pioneering work of 'Lover's cups' [9], numerous studies and developments have been made in intelligent mood lighting systems that reflect the interaction between human beings and their lighting environment [7]][8][9][10][11].

Emotional interaction using light has been made based on human actions through a wireless network in [9]. In [8], a facial expression system for robots was presented that utilizes diffent light areas for each part of the face. In [7], lights have a self-adaptive dimming mode, in which the lighting system changes based on the temperature through a ZigBee network. In addition, in regards to industry, many studies have been made on the effect of lighting and color on the human moods and emotions [10][11][12].

When developing intelligent LED mood lighting systems, we need to consider the physical LED lighting system, the wireless networks and integration, the analysis of the effects lighting has on the human body, recognition of human behaviors and emotions, and the color sequence generation methods. In regards to the LED lighting system itself, we need to analyze the relationship between the color sequence generated in the authoring tool and the actual resultant color generated by the LED lighting system. In addition, for the actual interface, human characteristics and the LED circuitry need to be taken into account.

In this paper, we present a new LED (Light Emitting Diode) mood lighting system interacting with smartphones based on the generation of different light sequences. We describe a personal generation method for the color sequences, and the relationship between the assigned color and the real LED color. In the proposed system, one light unit is generated for the transmission of emotion to the smartphone and LED lighting system. One unit controls a varying sequence of colors in order to express the intention and the emotion of the sender. The content is transmitted from the smartphone via a wireless network to the LED lighting system.

To this end, in this paper, we present a novel authoring scheme for smartphone along with the decoding and playing mechanism for the LED lighting circuit. Basically, one color sequence is repeated periodically. A sequence consists of a user-defined period and user-defined time units, each of which has a user-defined color. There are two modes : the basic mode and the interpolation mode. In the basic mode, the color is maintained up to the next time unit, whereas in the interpolation mode, the color is interpolated during the transition between the current time unit and the next following time unit. The sequence is decoded and played in the lighting circuit by changing the duty cycle of the PWM signal.

In order to demonstrate the validity of the proposed methods, we implemented a demonstration system consisting of smartphones, servers, and LED lighting systems.

The remainder of this paper is organized as follows. In Section 2, related works are briefly introduced. In Sections 3 and 4, we describe the basic concept of the presented system and the generation and playing mechanisms, respectively. In Sections 5 and 6, the implementation of the demonstration system and the experiment results are presented, respectively. The conclusion follows in Section 7.

2. Related Works

Since lighting systems are not only fundamental but are also utilized in various ways, numerous studies have been made regarding intelligent mood lighting systems. Changing the luminance or color in an LED lighting system can affect the mood and emotions of human beings and also can improve the efficiency of the lighting system.

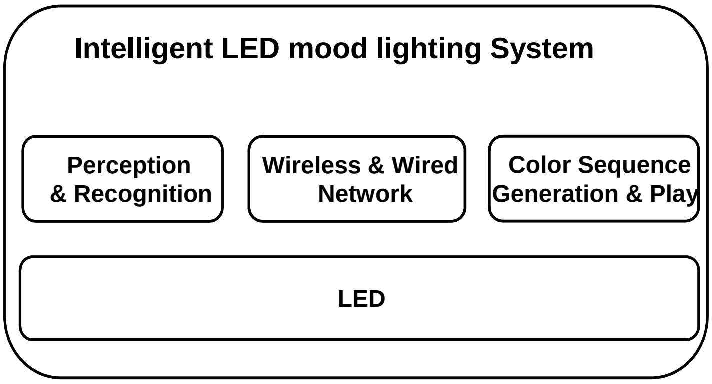


Fig. 1. The Characteristics of an intelligent mood LED lighting system.

For the emotional and intelligent lighting system, we need the network based system, adjustment of color or luminance considering human status, and recognition for the human behavior and emotion as shown in **Fig. 1**.

2.1 Network Based Intelligent Mood Lighting Systems

Recently, lighting systems have been connected to a network in order to procure flexibility according to the environment or human status.

In 'Lover's cups' [9] the information is transmitted to the LED through a wireless network. In [2], a smart LED system design methodology for weakly regulated voltage sources has been presented in order to minimize the fluctuations in human luminous perception. In [7], the lighting system is integrated with a ZigBee network. The lighting system can have several modes. Especially, in the self-adaptive dimming mode, the lighting system changes the intensity of the light based on the temperature or illumination.

2.2 Color and Intensity Variation for Intelligent LEDs in regards to Emotion

The adjustment of color and intensity in the lighting system has been analyzed in regards to their effect on human emotion and feelings.

The relationship between color and emotion was discussed in [12]. For example, bright colors evoke positive emotions, whereas dark colors bring about negative emotions.

The effects of lighting systems on mood and cognitive performance were discussed in [10] and [11].

3. The LED Mood Lighting System Using Color Sequence Generation

In this paper, we present a new LED mood lighting system interacting with smartphones based on the generation of lighting sequences. In addition, we present a generation method of the color sequences.

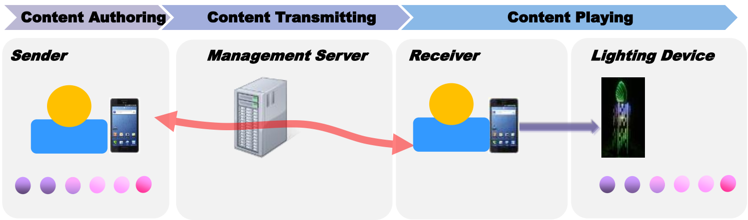


Fig. 2. The structure of LED mood lighting system consisting of smartphones, servers and LED lighting devices.

Fig. 2 shows the basic concept of the proposed system. A user can create LED lighting content using an application and send the lighting color sequence to the receiver. After receiving the content, it is decoded and played in the receiving LED circuit.

Each part of the system plays the following role:

1. Content Genetation : A unit of contents is made using the generation tool. The user can create a color variation sequence for the LED lighting system ; the sequence is compressed through the encoding tool.
2. Content Transmission : The user sends the created sequence directly to the receiver through the wireless network. Alternatively, the user can connect to the server and send a previously uploaded sequence to the receiver.
3. Content Execution : The color sequence is decoded. The LED circuit then analyses the sequence and displays the color according to the predefined mode for each time unit.

4. The Smartphone Color Sequence Generation and Execution in the LED Circuit

The color sequence needs to be created with the application and be displayed in the LED lighting device. Basically, we assume that the color sequence period is repeated in the LED lighting device. A color sequence is divided into user-defined time units. Each time unit has a starting color and a display mode. Using this, the LED lighting device then displays the color sequence employing the color and pattern that the user already selected.

4.1 Time-line Based Model for Generating a Color Sequence

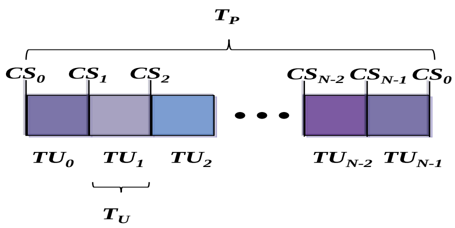


Fig. 3. The Generation model for a color sequence

Fig. 3 shows the generation model of a color sequence based on a time-line. We assume that the color sequence of a user-defined period is displayed repeatedly.

In **Fig. 3**, T_P, T_U, N, TU_i and CS_i denote the amount of time for a period, the size of a time unit, the number of time units in 1 period, each time unit according to index i, and the starting color for time unit TU_i, respectively. Here, $N=T_P/T_U$.

Each time unit TU_i can have its own starting color CS_i and one of the two modes, the basic mode or the interpolation mode. In the basic mode, the color does not change until the next time unit, whereas in the interpolation mode the color of current time unit TU_i is interpolated with that of the next time unit TU_{i+1}. For TU_{N-1}, the color is interpolated using the colors from TU_{N-1} and TU_0.

Therefore, we can obtain the equations for the color $C_i(t)$, (1) for the basic mode and (2) for the interpolation mode, according to time unit TU_i and starting color CS_i:

$$C_i(t) = CS_i, \qquad \text{for } 0 \le t \le T_U, \tag{1}$$

$$C_i(t) = CS_i + \frac{CS_{i+1} - CS_i}{T_U} \times t, \quad \text{for } 0 \le t \le T_U. \tag{2}$$

Fig. 4(a) and **Fig. 4(b)** show examples of the basic and interpolation modes, respectively.

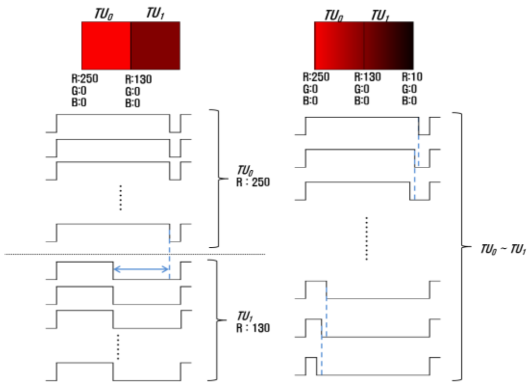
(a) The color variation in the basic mode

(b) The color variation in the interpolation mode

Fig. 4. The color variation modes

4.2 The Decoding and Display of the Received Color Sequence in the LED Circuit

The LED color change can be controlled by means of changing the duty cycle of a PWM pulse. After receiving the color sequence, we can discriminate the parameters for the display of a LED color. This color sequence is repeated utilizing the period, the time units and the playing modes.



(a) Basic mode (b) interpolation mode

Fig. 5. The PWM pulse variation according to the mode

Fig. 5 shows an example of the PWM pulse variations for the color sequence. After decoding the parameters for the color sequence, the color of each time unit is determined using (1) and (2) according to the corresponding mode.

Let us assume that for the LED Red, Green and Blue value are R=250, R=130 and R=10 for CS_0, CS_1 and CS_2, respectively, and G=B=0 for all CS_i.

Fig. 5(a) and **Fig. 5(b)** show the PWM pulse variations for each time unit in the basic mode and the interpolation mode, respectively. In the basic mode, the initial PWM width according to the CS_i is preserved during the time unit TU_i as determined using (1), whereas the PWM width is determined considering the interpolated color as determined using (2) for the interpolation mode.

Fig. 6 shows the pulse variation procedure more in detail for the circuit. With the period of 10ms, PWM width is determined according to the related colors and selected modes. Also, PWM module in MCU makes the duty cycle changed for the LED circuit.

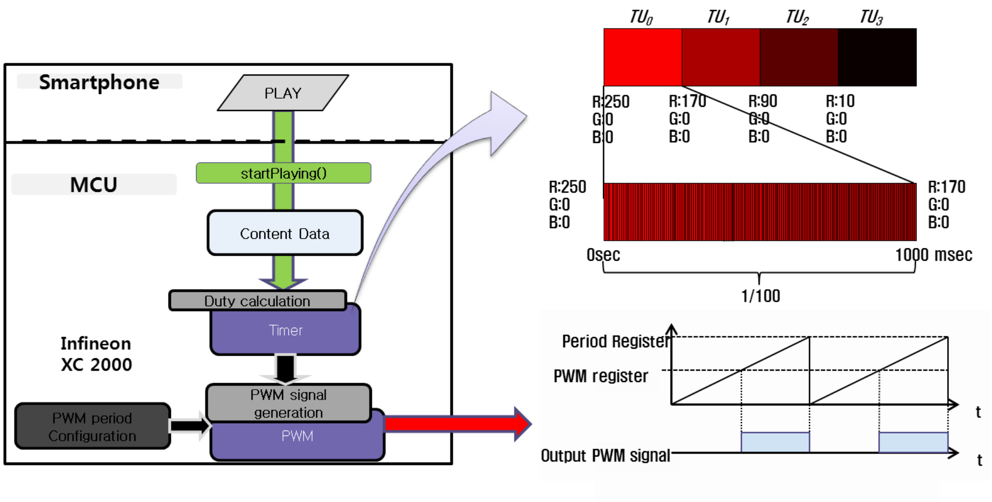


Fig. 6. PWM pulse variation in hardware circuit

For the basic mode, the detailed steps for the content play in LED circuit after receiving content are as follows:

- Step 1: Receive content and extract the related information for the play.
- Step 2: Read the current color information and determine the duty cycle of corresponding PWM module using $D = C_i(t)/255 \times 100$.
- Step 3: Adjust the duty cycle of the circuit based on the obtained value.

Also, for the interpolation mode, the steps are as follows:

- Step 1: Receive content and extract the related information for the play.
- Step 2: Read the current color information CS_i and the next color information CS_{i+1}.
- Step 3: Activate timer event as a period of 10ms.
- Step 4: When there is a timer overflow, calculate the corresponding color information using (2) based on the linear interpolation using CS_i and CS_{i+1}.
- Step 5: Determine the duty cycle of PWM pulse width from $C_i(t)$. The color value of R, G and B is from 0 to 255 and the corresponding duty is from 0 to 100%.
- Step 6: Adjust the duty cycle of the circuit based on the obtained value.

5. The Implementation of the Demonstration System Using Smartphones, Servers and LED Lighting Devices

We implemented a demonstration system for the LED mood lighting system consisting of smartphones, servers and LED lighting devices. Fig. 7 shows the overall structure of the demonstration system.

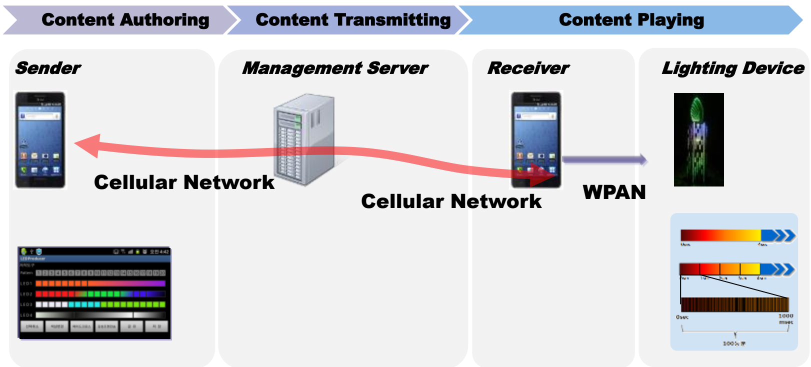


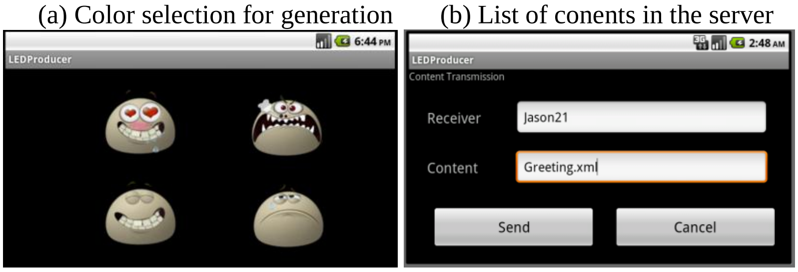
Fig. 7. The structure of the implemented demonstration system

A content unit is created fresh using the application in the smartphone or already has been saved to the server. The user can select a unit using the smartphone. The selected unit is delivered to the receiver's smartphone through the cellular network and is then transmitted to the LED lighting device through Bluetooth. Finally, the unit is displayed by the LED lighting device.

5.1 Smartphone Application for Message Sender

Using the smartphone application, we can create a content unit for the color sequence or connect to the server to select one of the previously uploaded units. As shown in Fig. 8., we can generate the chosen unit and send it to the receiver through SMS or a cellular data network

(a) Color selection for generation (b) List of conents in the server



(c) Predefined content in the circuit (d) Content transmission

Fig. 8. The smartphone application functions

Fig. 8(c) shows the predefined pattern stored in the LED circuit. Based on the results in [10]~[12], we define 4 mood patterns such as Love, Rage, Happiness and Sadness. Basic relationship between mood pattern and color is shown in **Table 1**. The LED patterns are shown in **Fig. 17**.

Table 1. Relationship between color and mood

Mood	Color
Love	Pink, Red
Rage	Black, Red, Purple
Happiness	Pink, Yellow, Cyan
Sadness	Purple, Black, Blue

Fig. 9 shows the generation tool for a color sequence in the smartphone. A color sequence can be made for each LED module. The generation algorithm is based on the ideas discussed in Section 4.

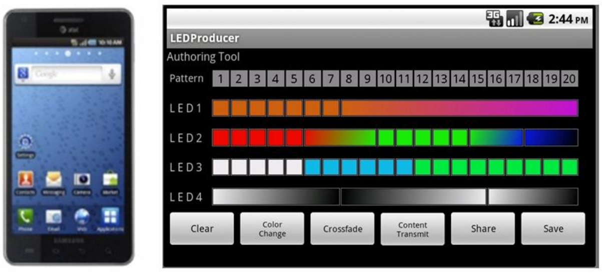


Fig. 9. Color sequence generation application for the smartphone

We used XML for LED color sequencer as shown in **Fig. 10**. The attributes of each time unit, which consist of the starting color and the display mode, are written in the content file as an XML file as can be seen in **Fig. 10**.


```xml
<?xml version="1.0" encoding="utf-8"?>
<LED xmlns:emoLED="http://smart.kookmin.ac.kr/schemas/emoLED">
  <LED1>
    <TimeBlock value="1" effect="0" spectrumState="0" currentColor="0xff000000"></TimeBlock>
    <TimeBlock value="2" effect="0" spectrumState="0" currentColor="0xff000000"></TimeBlock>
    <TimeBlock value="3" effect="0" spectrumState="0" currentColor="0xff000000"></TimeBlock>
    <TimeBlock value="4" effect="0" spectrumState="0" currentColor="0xff000000"></TimeBlock>
    <TimeBlock value="5" effect="0" spectrumState="0" currentColor="0xff000000"></TimeBlock>
  </LED1>
  <LED2>
    <TimeBlock value="1" effect="0" spectrumState="0" currentColor="0xff230000"></TimeBlock>
    <TimeBlock value="2" effect="0" spectrumState="0" currentColor="0xff560000"></TimeBlock>
    <TimeBlock value="3" effect="0" spectrumState="0" currentColor="0xff005400"></TimeBlock>
    <TimeBlock value="4" effect="0" spectrumState="0" currentColor="0xffa40000"></TimeBlock>
    <TimeBlock value="5" effect="0" spectrumState="0" currentColor="0xff004500"></TimeBlock>
  </LED2>
  <LED3>
    <TimeBlock value="1" effect="1" spectrumState="11" currentColor="0xffff0000"></TimeBlock>
    <TimeBlock value="2" effect="1" spectrumState="12" currentColor="0xff000000"></TimeBlock>
    <TimeBlock value="3" effect="1" spectrumState="12" currentColor="0xff000000"></TimeBlock>
    <TimeBlock value="4" effect="1" spectrumState="12" currentColor="0xff000000"></TimeBlock>
    <TimeBlock value="5" effect="1" spectrumState="13" currentColor="0xff0000ff"></TimeBlock>
  </LED3>
  <LED4>
    <TimeBlock value="1" effect="0" spectrumState="0" currentColor="0xff000000"></TimeBlock>
    <TimeBlock value="2" effect="0" spectrumState="0" currentColor="0xff000000"></TimeBlock>
    <TimeBlock value="3" effect="0" spectrumState="0" currentColor="0xff000000"></TimeBlock>
    <TimeBlock value="4" effect="0" spectrumState="0" currentColor="0xff000000"></TimeBlock>
    <TimeBlock value="5" effect="0" spectrumState="0" currentColor="0xff000000"></TimeBlock>
  </LED4>
</LED>
```


Fig. 10. An example of a color sequence content file

5.2 The Management Server

The management server handles the content files, such as seen in **Fig. 10**. One can upload the created files to the server, connect to the server, select a content unit, and then send it to the receiver.

5.3 The Receiver Smartphone Application

The smartphone applications for the sender and the receiver are the same. In regards to the receiver, the smartphone application receives the content file and sends it to the LED device.

Depending on the smartphone platform or environment, we can use 'push' or 'polling' mechanisms to receive the content file. Regardless of the mechanism, we receive the content file as soon as it is transmitted by the sender through the cellular data network. The information is decoded from XML file and is transmitted to the LED lighting device in order to display the color sequence.

Fig. 11 shows the communication process between the smartphone and the LED lighting device.

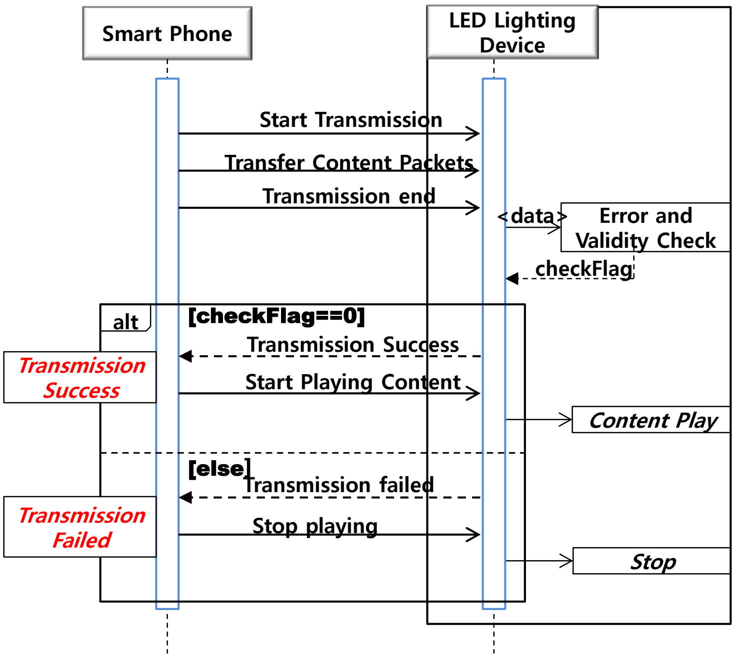


Fig. 11. The Communication process between the smartphone and the lighting device

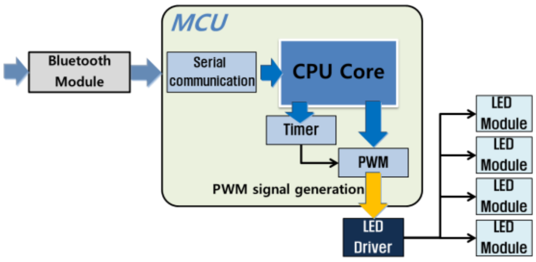
5.4 The LED Lighting Device

The implemented LED lighting device consists of an external framework for the device, a Bluetooth module for communication with the smartphone and an MCU (Micro-Controller Unit) based LED module. The external framework is made by D&CI. Infineon XC 2287 MCU has been used for the control of LED module.

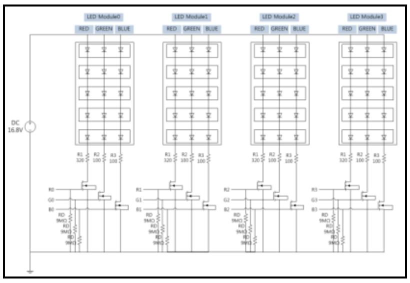
Fig. 12 shows the overall hardware architecture of the intelligent LED mood lighting device. As shown in **Fig. 12(a)**, the lighting module receives the color sequence information from the smartphone and displays the designed color sequence. **Fig. 12(b)**, **Fig. 12(c)** and **Fig. 12(d)** show the LED module circuit diagram, implemented circuit for the LED module and external framework and device, respectively. The LED module has four LED components, each of which can be controlled independently. The location of each LED component is different from each other. Among them, the component in the highest position displays its color through the candle flame as shown in **Fig. 12(c)** and **Fig. 12(d)**.

In order to support four LED components and true color (Red, Green and Blue), twelve

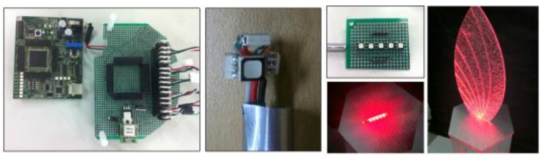
PWM signals need to be generated for the module. **Fig. 12(a)** shows the overall process of the LED lighting device from smartphone to LED display.



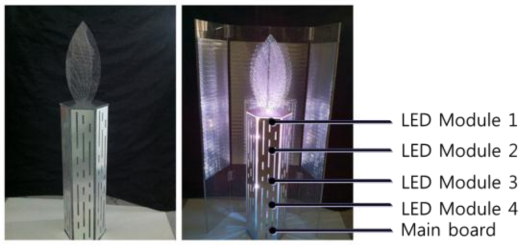
(a) The LED lighting module block diagram



(b) The LED lighting module circuit diagram



(c) The LED lighting module



(d) The LED framework and device

Fig. 12. The LED lighting device structure

6. Experimental Results

Fig. 13 shows the experimental setup for the proposed system. The color sequence generated from authoring tool in smartphone can be directly transmitted to the receiver's smartphone or can be uploaded to the server. For the connection between smartphone and LED device, Bluetooth has been utilized.

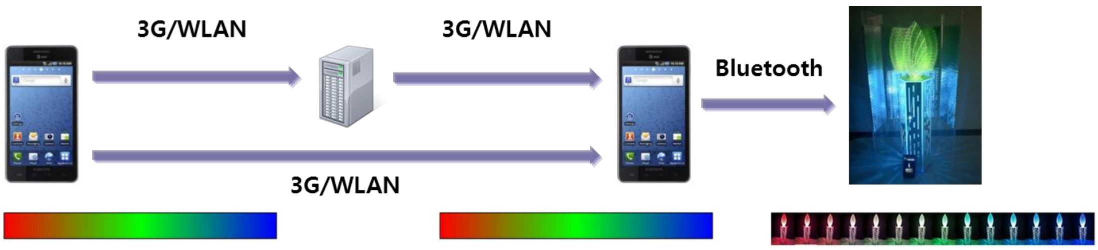


Fig. 13. Experimental setup of the proposed system

Fig. 14 shows pictures of the LED lighting device after a color sequence is transmitted from the smartphone. The implemented system has four independent LED components which can provide various effects in the display

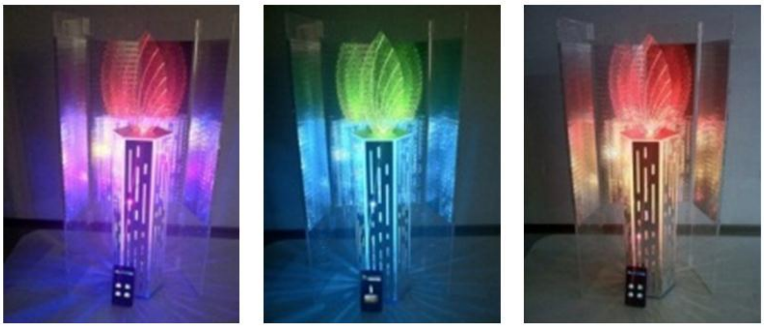
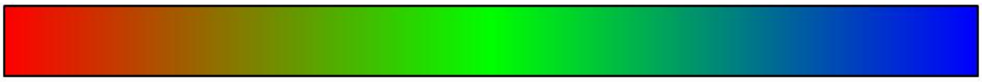
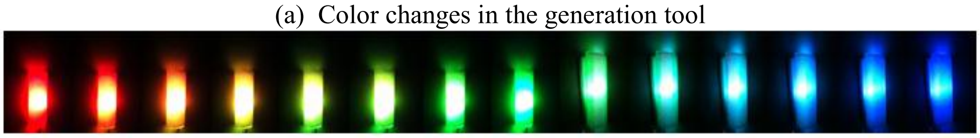


Fig. 14. Examples of the color sequence display

Fig. 15 and **Fig. 16** show the relationship between the color seen in the generation tool and the real color generated by LED lighting device.



(a) Color changes in the generation tool



(b) Color changes in the LED module

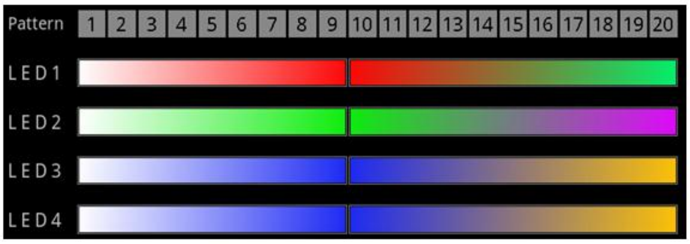
(c) Color changes in the LED lighting device

Fig. 15. A comparison of the color changes in the generation tool, LED module and lighting device

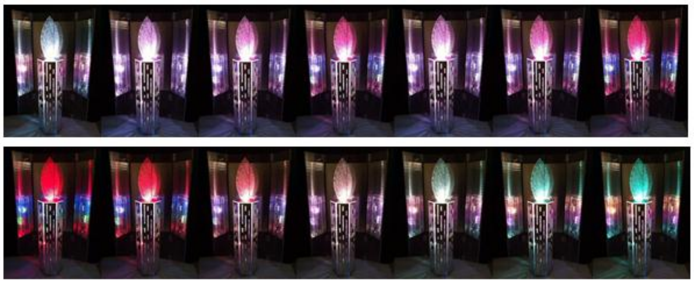
In order to show the mapping from the color in the generation tool and the real LED color, **Fig. 15** shows the color sequence from the generation tool and pictures of the LED display. **Fig. 15(a)** shows the color in the generation tool, whereas **Fig. 15(b)** and **Fig. 15(c)** show the real color from the LED and lighting device, respectively. We took the 14 pictures of the LED, one every second over 14 seconds. In reality, the color of the LED module changes continuously, as it does in the generation tool.

Since the four LED components can be controlled independently in the designed LED lighting device, various effects can be achieved. **Fig. 16** shows an example of different color sequences for each LED component.

Fig. 17 shows changes in the colors and PWM signals. As shown in **Fig. 17(a)**, the color changes from Red to Green. From **Fig. 17(b)** to **Fig. 17(f)**, the corresponding PWM signals are shown for time units 2, 6, 11, 16 and 19. We can observe that the signals are generated adequately.

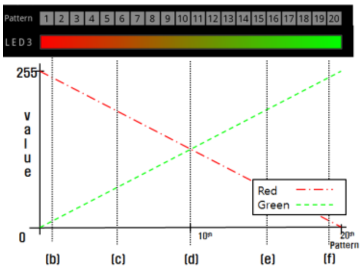


(a) Color changes in the four LED components

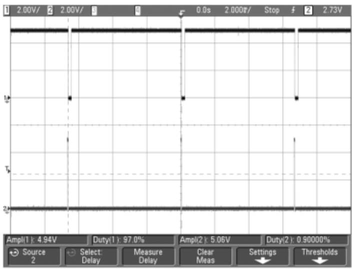


(b) Color changes in LED lighting device

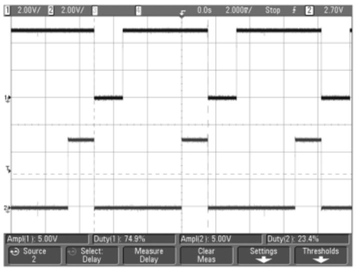
Fig. 16. A comparison of the color changes in the generation tool and the lighting device for different color sequences using the four LED components



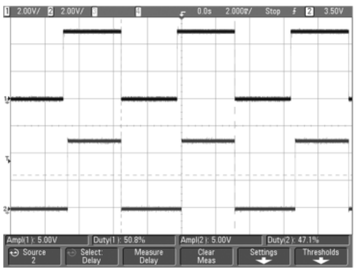
(a) The order of Pattern vs. The value of RGB



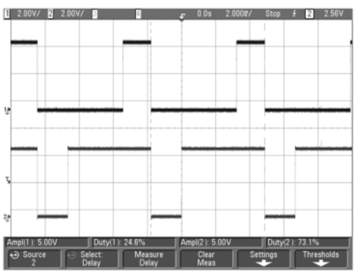
(b) Red Duty : 97.0%, Green Duty : 0.9%
Red voltage : 4.94v, Green voltage : 5.06v



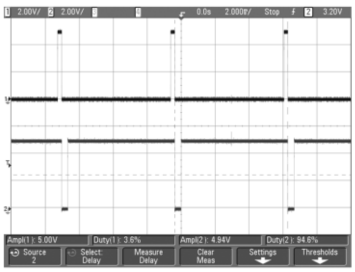
(c) Red Duty : 74.9%, Green Duty : 23.4%
Red voltage : 5.00v, Green voltage : 5.00v



(d) Red Duty : 50.8%, Green Duty : 47.1%
Red voltage : 5.00v, Green voltage : 5.00v

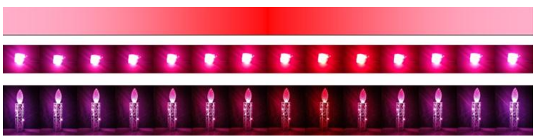


(e) Red Duty : 24.6%, Green Duty : 73.1%
Red voltage : 5.00v, Green voltage : 5.00v

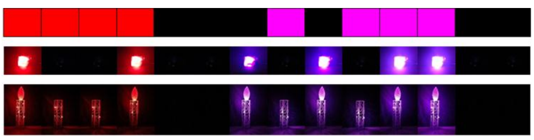


(f) Red Duty : 3.6%, Green Duty : 94.6%
Red voltage : 5.00v, Green voltage : 4.94v

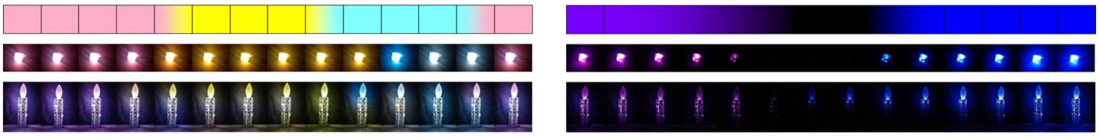
Fig. 17. PWM signals corresponding to the color sequence**.**



(a) Love



(b) Rage



(c) Happiness (d) Sadness

Fig. 18. Sample mood patterns

Fig. 18 shows the sample mood patterns which is stored already in the LED circuit. According to **Table 1**, four color patterns are generated according to the command from the smartphone.

Through the overall experiment, it has been shown that the presented system works well in the aspect of both color sequence generation in smartphone and content play in the circuit.

For the future research, more comparison and analysis between the color in the smartphone and the color in LED module should be made. Recognition of the human mood is required for the intelligent mood lighting system. Also, considering the energy consumption in the LED module, energy-efficient design and optimization are also needed in LED circuit.

7. Conclusion

In this paper, we presented a new intelligent LED mood lighting system interacting with smartphones and wireless networks based on the generation of color sequences. In the presented system, a sequence of color is considered to be a service content unit which can be transmitted to another user's LED lighting device through a wireless network.

To achieve this end, we proposed a novel generation method of the color sequence for the module. A color sequence is composed of several time units; each unit has a starting color and a display mode. Based on this, a color sequence is encoded to produce a lighting content unit. It is transmitted to the receiver's smartphone and lighting device. After the transmission, the sequence is decoded in the lighting circuit and played by means of changing the duty cycle of the PWM signal. From the implementation and experiment of the proposed method using smartphones, servers and LED lighting systems, we have shown that the proposed method works appropriately in the intelligent LED mood lighting system.

Currently, we are developing a more efficient and intuitive method for the generation of the color sequence using a palette and touch commands in a smartphone and a tablet. More research is required into the effect of color sequences on the human beings and the natural display of color sequences in LED lighting devices. These issues remain to be studied in future works.

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