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New LEDs improve the quality of illumination of full-color holograms recorded with red 660 nm, green 532 nm and blue 440 nm lasers

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Abstract

This paper discusses the main requirements in today's full-color holograms illumination and evaluates the last generation of LEDs, the actual best light source to render properly the colors of the holograms and in particular those recorded with red 660 nm, green 532 nm and blue 440 nm lasers. This paper presents also the first prototype of lamp designed especially for this kind of holograms.

Keywords: *Holography, Full-color hologram, Digital holography, Holoprint, Diode*

1. INTRODUCTION

The choice of the lightning source is critical in holography [1-4], and even more in for full color reflection holograms, because the light must be punctual and should generate the wavelengths of the original recording lasers. Furthermore it should be placed at the right angle and position facing the hologram. During many years, only a halogen lamp was the solution for indoor illumination, but like the color balance was wrong due to the lack of blue, the color holograms were not perfectly reconstructed. The LEDs (light-emitting diode) [5] then offer a much better solution for color holography: their wavelengths are centered on the lasers wavelengths, no unwanted colors exist that usually create diffusion, and the possibility to adjust the color balance after the recording of the RGB color hologram can be very useful. But until now there was no such LEDs available for full-color holograms recorded with blue 440 nm and red 660 nm wavelengths. This paper evaluates two new types of LEDs now available on the market: the “Royal Blue” centered on 440 nm and the “Deep Red” centered on 660 nm, which could offer finally a solution for this type of holograms. This paper presents also a first prototype of lamp using these two wavelengths.

2. LASERS AVAILABLE IN FULL-COLOR HOLOGRAPHY

There are two main types of lasers used in full-color holography: the continuous (gas or/and DPSS) lasers and the pulsed lasers (used mainly to record digital hologram). A large choice of wavelengths is available for

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continuous (gas or/and DPSS) lasers. Wavelengths usually used, are 440 nm, 457 nm or 473 nm for blue, 532 nm for green and 633 nm, 639 nm, 647 nm and 660 nm for red (Fig. 1.a). There are also several manufacturers for this type of lasers which are now affordable. On the other hand few types of commercially available pulsed lasers exist at this time in the visible range: the wavelength of the blue laser is 440 nm and 660 nm for the red. The green color can be 532 nm or 526 nm (Fig. 1.b). They are mostly used for fast printing of digital full-color holograms and are quite expensive [6].

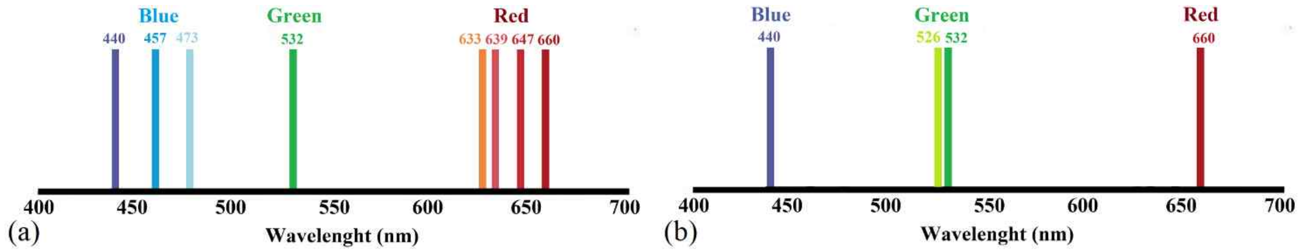

Figure 1. Wavelengths available for continuous (gas or/and DPSS) lasers (a) and for pulsed lasers (b)

3. FULL-COLOR HOLOGRAMS ILLUMINATION

Color accuracy of the reconstruction stage of full-color digital or analog holograms, compared to the original object, depends on the source of illumination (daylight, halogen, LEDs…) and on the wavelengths of the lasers used during the recording. The color rendering is the same whether it is an analog or digital hologram. The only important factor is the choice of the three wavelengths [7] used to record the full-color hologram and not the recording technique. We compared the color rendering of the images with different light sources (daylight, halogen, cool white LEDs, warm white LEDs and RGB LEDs), for two full-color holograms: the first one recorded with a common RGB combination of lasers (473 nm, 532 nm and 633 nm), the second recorded with the available RGB combination of pulsed lasers (440 nm, 532 nm and 660 nm).

3.1 Illumination of a full-color hologram recorded with a RGB (473+ 532+633) combination of continuous lasers

An analog hologram was recorded on Ultimate 04 (U04) [8-9], a high sensitivity silver-halide holographic material, with the following wavelengths: 473 nm for blue (DPSS), 532 nm for green (DPSS) and 633 for red (HeNe). U04 is iso-panchromatic for all the visible wavelengths, except in the greenish-yellow range. The 10x13 cm hologram was recorded with the three wavelengths simultaneously and with a balance ratio 1:1:1. The hologram looks great and colorful when it is illuminated with daylight (Fig. 2.a). The daylight spectrum shows that all the wavelengths (473, 532 and 633 nm) are present in a large intensity (Fig. 2.b). The hologram looks good enough when illuminated with halogen but the blue colors are not vivid and white color looks yellow. The color balance is not correct, and the hologram is reddish (Fig. 2.c). The halogen spectrum shows that the blue wavelengths 473 nm (like the blue 457 nm) has a small intensity compare the red and green wavelengths (Fig. 2.d). The hologram is still good when illuminated with cool white LEDs, but the image looks greenish-bluish (Fig. 2.e) and present some blur and diffusion. The cool white LEDs spectrum shows that there is not enough red 633 nm and too much blue 473nm (and 457) (Fig. 2.f). With warm white LEDs, the hologram looks bichrome (Fig. 2.g). The color balance between red and green is good, but there are nearly no blue colors. The Warm White LEDs spectrum shows that there is not enough blue 473 nm (and 457 nm) (Fig. 2.h).

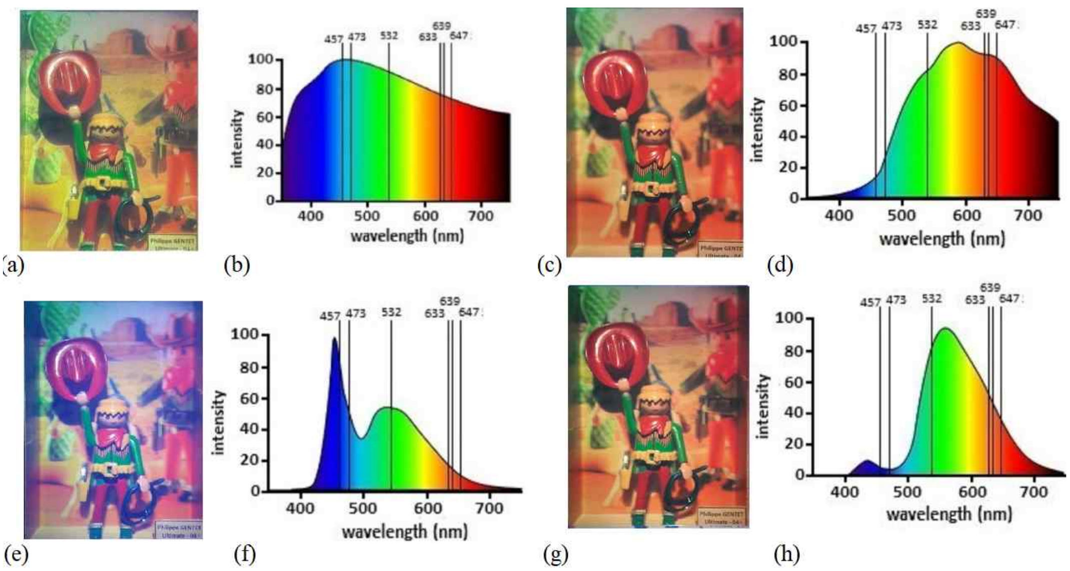

Figure 2. Hologram illumination with daylight (.a), daylight's spectrum (b), illumination with halogen (c), halogen's spectrum (d), illumination with cool white LEDs (e), cool white LEDs spectrum (f), illumination with warm white LEDs (g) and warm white LEDs spectrum (h)

When illuminated with RGB LEDs, the recorded hologram looks much better and clear that with any other kind of the previous lamps (Fig. 3.a). There are no diffusion and no noise and the color balance is good. The white looks "white". The typical RGB LEDs available in the market are narrow bands and have three spikes: a "bright red" 630 nm, a "pure green" 530 nm and a "bright blue" 460 nm (Fig. 3.b). But experience also shows that different RGB LEDs lamp from a same batch can give slightly different results for the color balance.

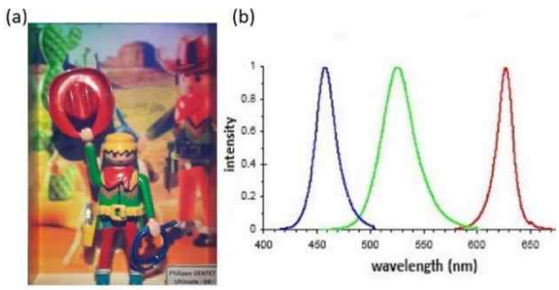

Figure 3. Hologram illumination RGB LEDs (a) and RGB LEDs spectrum (b)

3.2 Illumination of full-color hologram recorded with a RGB (440+ 532+660) combination of pulsed lasers

We recorded a full-color pulsed digital hologram (Holoprint) on Ultimate U08-P an ultra-high sensitivity silver halide holographic material specially designed for pulsed lasers, with the following wavelengths: 440 nm blue, 532 nm green and 660 nm red. U08-P is iso-chromatic for these 3 wavelengths [9]. This 15x25 cm Holoprint was recorded with the 3 wavelengths simultaneously with a ratio 1:1:1. The hogel (holographic element) size of this holoprint is 0.5 mm. With daylight illumination, the image looks greenish: the red and blue colors of the recorded hologram are not vivid (Fig. 4.a), although the daylight's spectrum shows that the 3 wavelengths (440, 532 and 660) are present with good intensity (Fig. 4.b). The holoprint looks very greenish when illuminated with halogen. There is almost no visible blue and like with the daylight, the red color looks dark (Fig. 4.c). The halogen spectrum shows that the blue wavelength 440 nm has a small intensity compare the red 660 nm and green 532 nm (Fig. 4.d). In accordance with the cool white LEDs spectrum (Fig. 4.e) which indicates a more intense blue with a bright green and almost no visible red, the holoprint appears blue-green (Fig. 4.f). Blue is as bright as green with this cool white LED. The holoprint appears greenish (Fig 4.g) when illuminated with a warm white LED. In the warm white LEDs spectrum there is almost no blue and not enough red (Fig. 4.h).

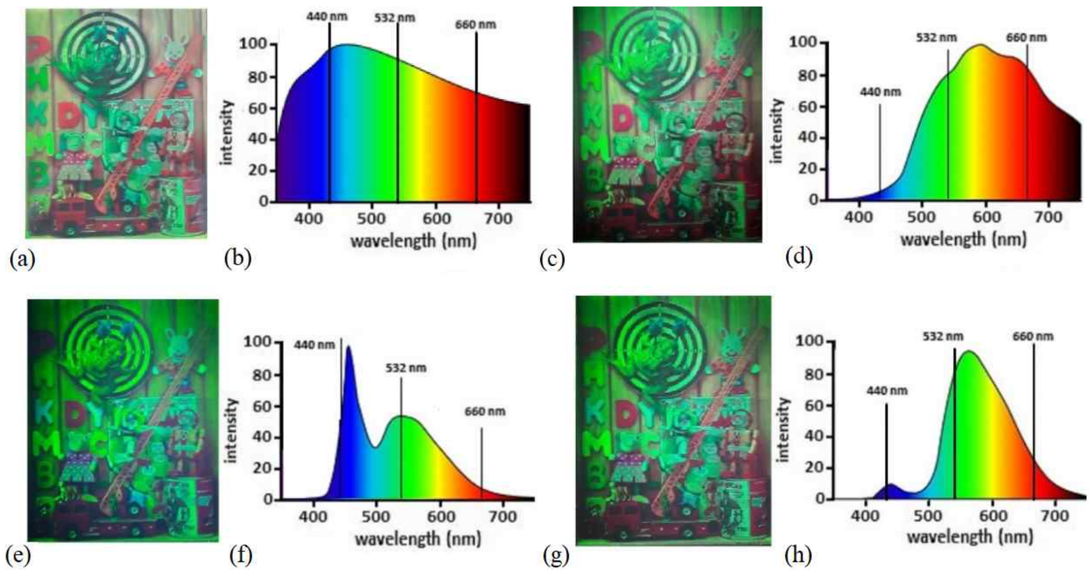

Figure 4. Holoprint illumination with daylight (a), daylight's spectrum (b), illumination with halogen (c), halogen's spectrum (d), illumination with cool white LEDs (e), cool white LEDs spectrum (f), illumination with warm white LEDs (g) and warm white LEDs spectrum (h)

In contrary of the holograms recorded with continuous lasers, there is no RGB LEDs in the market with the correct blue (440 nm) and red (660 nm) wavelengths. After some research we identified two new LEDs available today that allowed us to build our own RGB LEDs lamp, with a "Royal Blue" LED (440-455 nm) and a "Deep Red" LED (650-670 nm). The principle spectrums of the existing LEDs are shown on Figure 5.

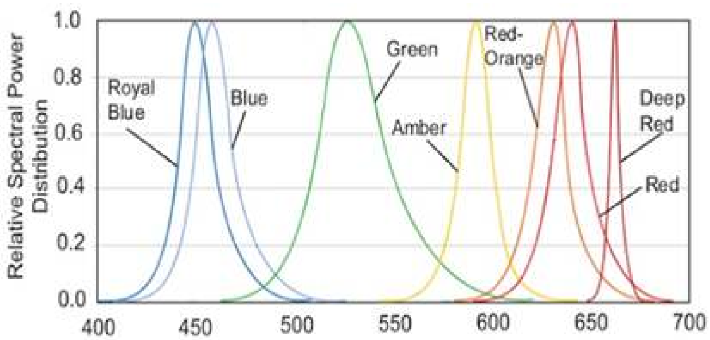

Figure 5. Principle spectrums of the existing LED

Our RGB LED lamp is built with 3 LEDs of one watt: one "Deep Red" (650-670 nm), one "Green" (520-530 nm) and one "Royal Blue" LED (440-455 nm). The 3 beams (red, green and blue) are mix together from three directions into one direction with a cross dichroic prism (X-cube) RGB combiner (Fig. 6.a and 6.b).

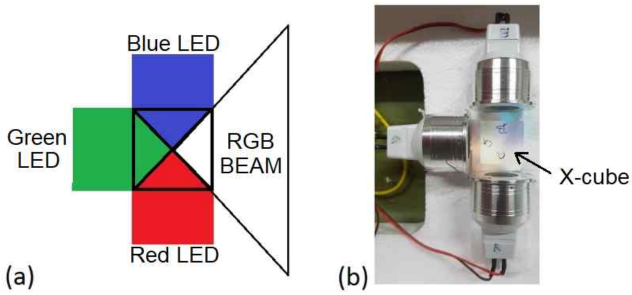

Figure 6. The 3 LEDs are combining together with a cross dichroic prism RGB combiner: diagram (a) and picture (b)

With this new lamp, when illuminated with a single color, three strong red hologram (Fig. 7.a), green hologram (Fig. 7.b) and blue hologram (Fig. 7.c) are getting, but the color balance is still not good. The red looks darker when mixed with the two other colors (Fig. 7.d).

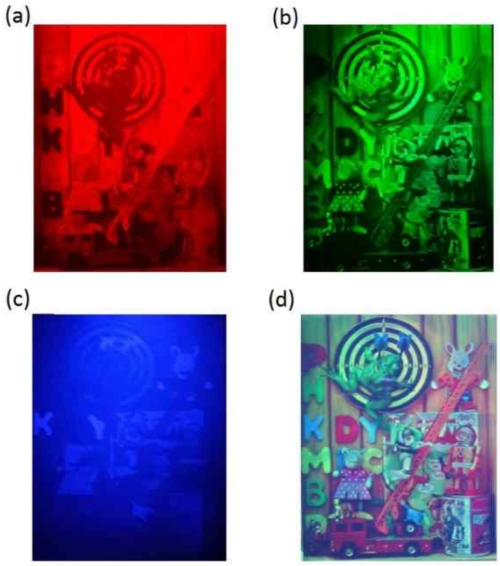

Figure 7. Holoprint illumination with RGB LEDs: red (a), green (b), blue (c) and RGB hologram (ratio 1:1:1) (d)

These different experiments show us that there is a real difficulty to illuminate properly a hologram recorded with a red 660 nm, whatever the source of illumination, contrary to the holograms recorded with a red 633, 639 or 647 nm. For this reason we decide to add a "Color Control System" to our lamp to get the correct balance between the three RGB colors.

4. LEDS COLOR CONTROL SYSTEM

This LEDs color control system can independently control the red, green, and blue LED and can maintain optimal lighting conditions by varying the intensity of each color (Fig. 8).

Figure 8. LEDs color control system configuration

The color controller consists of Power, CPU, Clock, Output Control, and Communication (Fig. 9.a). Power supplies the necessary power for operation, and Clock generates the synchronization signal necessary for CPU operation and supplies it to the CPU. The Communication part receives the data of the received RGB color intensity according to the defined protocol and delivers it to the CPU. In the GUI (Graphical User Interface), each color can be adjusted easily from 0 to 100 % with the 3 RGB Color Level Bars (Fig. 9.b).

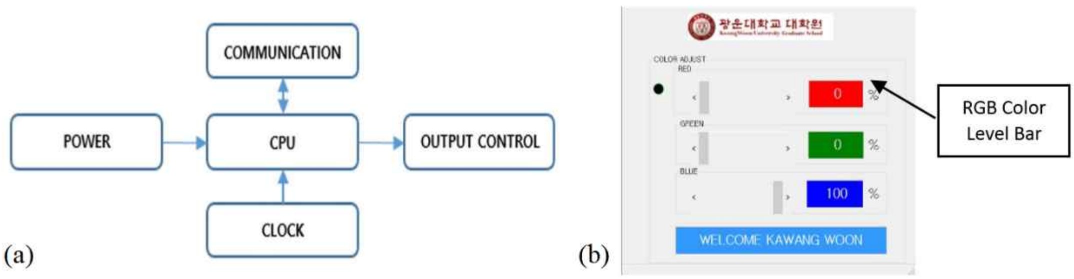

Figure 9. LEDs Color controller components (a) and Graphical User Interface (b)

The timing diagram of the PWM (Pulse Width Modulation) control pulse explains the operating principle (Fig. 10).The value set through GUI in PC generates control pulse data for LED control according to each value of RGB. The frequency of the generated control pulse is fixed and the brightness of the LED is changed by controlling the duty rate. In other words, the control pulse changes the average brightness of the LED by controlling the duty ratio for turn on timing of the pulse by the PWM method.

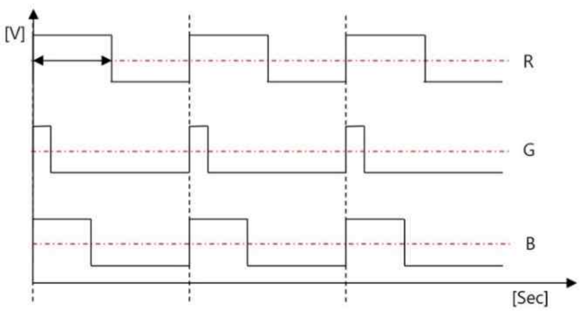

Figure 10. Timing diagram of PWM control pulse

5. RESULTS AND DISCUSSION

The full-color hologram recorded with blue 440 nm, green 532 nm and red 660 nm is now illuminated with the new RGB LED lamp equipped with the color control system. Experience shows that it is necessary to reduce the green and the blue colors to get the right color balance. With this particular lamp the ratio is 5 for red, 1 for green and 1 for blue (5:1:1). With these good proportions, the color balance is better than for the ratio 1:1:1 (Fig. 11.a) and all the colors become very bright, and the color palette increases: pink and violets become vivid (Fig. 11.b). Now that the ratio is determined, it is possible to obtain a brighter hologram by making a more powerful lamp composed of five red LEDs for one green LED and one blue LED.

(a) (b)

Figure 11. Holoprint (440+532+660) illumination with RGB LEDs, with a ratio 1:1:1 (a) and 5:1:1 (b)

The biggest difficulty for the holograms illumination comes from the wavelengths used for the recording. The human color vision theory makes it possible to explain the phenomenon observed with holograms recorded with the three wavelengths: 660 nm, 532 nm and 440 nm. Color vision is the ability to distinguish objects based on the wavelengths of the light they reflect, emit, or transmit [10]. Color's perception is a subjective process where the brain of a person responds to the stimuli produced when incoming light reacts with the cone cells in the eye: the difference in the signals received from the three cone types [11] allows the human brain to perceive a continuous range of colors. The normalized responsivity spectra of human cone cells (Fig.12) shows that the L cone has peak near 564–580 nm, the M cone near 534–545 nm, and the S near 420–440 nm (depending on the people). Normalized responsivity spectrum of human cone cells study shows that above 650 nm human eye has very little response (only the cone L reacts). This explains why it is necessary to increase the ratio of red 660 nm to that of blue 440 nm and green 532 nm where the response is maximal to get colorful hologram. For hologram recorded with red 633 to 647 nm, the human eye response is good because both cones L and M react: it is therefore not necessary to increase the proportion of red in the RGB LED spot.

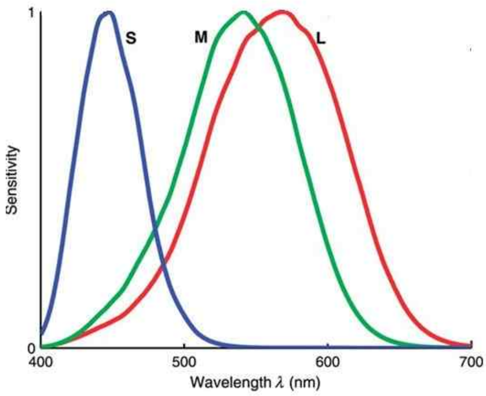

Figure 12. Normalized responsivity spectrum of human cone cells

A first solution to compensate for the lack of red 660 nm, would be to decrease the proportion of green when recording the hologram with the lasers to achieve a better color balance. When the full-color hologram is recorded, in fact three holograms are recorded simultaneously with the same energy in the isopanchromatic emulsion: a blue hologram, a green hologram and a red hologram. This is why, if the power of the green laser is lowered during recording, the green hologram becomes very dim. The response function curve of the human eye shows that green light contributes the most to the intensity perceived by people (Fig. 13). So a color hologram with a dim green color always looks dark when correctly balanced.

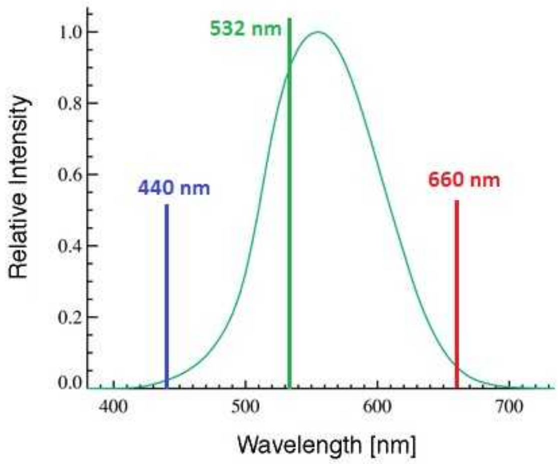

Figure 13. The response function of the human eye

It can be summarized that for any full-color hologram: the green hologram gives the brightness, the red hologram renders the colorization effect but contribute few to the brightness and the blue hologram gives the white but does not increase the brightness at all. Therefore decreasing the proportion of green during recording decreases the final brightness of the hologram.

A second solution is to change colors of a hologram by changing the angle of reconstruction of the lamp. If the halogen spot angle is changed 10 ° upwards, the red 660 nm becomes a red 640 nm brighter for human eyes although its intensity remains the same and the blue 440 becomes a blue 420 nm nearly invisible for human eyes. If the halogen spot is moved 10 ° downwards the red 660 becomes a red 680 invisible for human eyes and the blue 440 becomes a blue 460 very bright for human eyes. With these 3 specific wavelengths (440 nm, 532 nm and 660nm) it is therefore not possible to modify the reconstruction angle of the spot without losing one of the 3 colors. Furthermore shifting the green creates a "pastel effect" of the colors, which become de-saturated and lacking strong chromatic content.

To illuminate the holograms the best choice possible today is the RGB LEDs and it's very important to choose LEDs with the same wavelengths as those of the lasers used during the recording. The LEDs' spectral characteristics are primarily determined by their junction structure with emissions tuned to a primary wavelength during the manufacturing process. This means that the LEDs of the same batch may have a different peak for their wavelengths (for example green LEDs can range from 520 nm to 540 nm) and this affects the RGB ratio of the final RGB LED.

6. CONCLUSION

Full-color holograms recorded with red lasers wavelength from 633 to 647 nm have always been able to be illuminated more or less faithfully, first with halogen lamps and then with the new generations of white (cool and warm) and RGB LEDs. But for full-color holograms recorded with red 660 nm lasers (in particular associated with blue 440 nm), there was no satisfactory solution for illumination. The final hologram appears always greenish with all conventional lighting systems. Thanks to the appearance of the LEDs "Royal Blue" (440-455 nm) and "Deep Red" (650-670nm), it is possible for the first time to properly illuminate this kind of hologram by the manufacture of a specific RGB lamp. This RGB lamp is composed of several blue, green and red LEDs whose spikes are selected closed at 440, 532 and 660 nm. A good ratio is typically 5 red 660 LEDs to 1 blue and 1green LEDs. Like all LEDs are different, that the perception of colors is specific to each person and there is a specific variation to each hologram, it is it is mandatory to be able to regulate electronically and independently the intensity of each color, with buttons or a remote control as for the screen of a television, to get the best rendering.

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