Spectroscopic Colour Evaluation under Different White Light Emitting Diode Illumination Angle

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Abstract. Colour appearance can vary according to object material, geometry, surface characteristics and lighting conditions. In this study, a visible spectroscopy system using white LED as light source is used to measure the reflectance of colour paper at several different illumination angles of 15°, 30°, 45°, 60°, and 75°. In this experiment light was reflected from the surface of colour papers and was captured by spectrometer yielding in spectra ranging from 380 nm to 780 nm. Obtained spectra were plotted as a scatter plot to get the spectral gradient curves for each colour series. Peak wavelengths were also determined to check the shift in wavelength at different conditions. In this work influence of illumination angle on measurement of colour of a colour paper in spectral responsivity is showed. The best responsivity was obtained when light source of 5700 K white LED was illuminated at angle of 60° for blue and green colour series with spectral gradient values of 0.573 (blue glossy), 0.577 (blue non-glossy), 0.245 (green glossy) and 0.214 (green non-glossy) respectively while 3500 K white LED was found to be a better light source at 60° illumination angle in red colour series measurement with spectral gradients of 0.171 (red glossy) and 0.159 (red non-glossy). Choice of white LED in term of CCT was also found to affect the peak wavelengths of the colour as measured by spectrometer.

1. Introduction

Colour is defined to be the subjective appearance of light as detected by human eye and plays an important role in human visual experience [1]. While human vision system is more flexible as compared to instrument as eye is sensitive to geometric factors such as direction, pattern and shape of the object; however, the drawbacks are that evaluation is a subjective matter as different observers observe differently and might even change according to viewing conditions. Therefore, it is advantageous to use instrument as repeatable measurements can be made regardless time and place although only a specific attribute can be taken at a time [2].

In fact, colour cannot be measured as colour is just a perceptual quality and hence, colour measurement actually refers to measuring of optical properties of a sample such as reflectance, absorbance and transmittance [3]. Colour measurement using visible spectroscopy across 380 to 780 nm spectral range in the electromagnetic spectrum has been widely applied in the past years. A spectroscopic system consists of a light source, a spectrometer, and a fiber optic cable. Light interacts with sample and sends back portion of the light via fiber optic cable to be analyzed by spectrometer. Spectrometer is considered as the heart of whole instrumentation system. Fiber optic sensor collects portion of the electromagnetic radiation after interaction with internal structure of sample and then transfers it to the spectrometer. The device will split up the sample light beams into their spectral components and will
digitize the signal as a function of wavelength and final data is observed in the form of a spectrum on a computer screen. The standard light source used in previous works was tungsten-halogen lamp with continuous spectrum from ultraviolet to infrared region in the electromagnetic spectrum which is comparable to the electromagnetic spectrum of Sun. Light Emitting Diode (LED) has been the rising star in lighting industry with higher efficiency, better light quality and lower energy consumption [4]. LED lighting market is growing continuously and will impact general lighting the most in 2020 [5].

Colour can be determined by the reflected light from a surface of an object, however, amount of light reflected from an object is regarded to vary according to the wavelength of the light, direction of the incident light on object (illumination angle) and direction from which the angle is viewed [2]. Therefore, this work is a preliminary study to determine the effect of illumination angle on colour measurement under two different white LED CCTs illuminations using visible spectroscopy.

2. Methodology
Experimental setup for this study consisted of a Jaz spectrometer (Ocean Optics Inc., Florida, USA), an optical fiber connecting spectrometer to computer and white LED lighting panels. The samples used for colour evaluation were monochromatic red, green and blue colour series papers in increasing hue from 20 to 255 printed on two types of paper; the glossy (G) and non-glossy (NG) ones. These colour papers were illuminated under white LEDs with different CCTs of 3500 K (D35) and 5700 K (D57) at illumination angles of 15º, 30º, 45º, 60º, and 75º respectively as shown in figure 1. The fiber optic probe was placed perpendicularly to sample at a fixed distance of 1.0 cm. White LED specifications are presented in table 1.

![Figure 1. Experimental setup.](image)

| Correlated Colour Temperature (K) | D35 | D57 |
|-----------------------------------|-----|-----|
| Product Type                      | LCW W5AM-KXXY-409Q | LUW W5AM-KYLX-4E8G |
| LED Colours                       | Warm White | Cool White |
| LED Material                      | GaN | InGaN |
| Luminous Flux (lm)                | 71-97 | 82-130 |
| Luminous Intensity(mcd)           | 19000-22000 | 22400-30200 |
| CRI                               | 80 | 70 |
Prior to measurement, Jaz spectrometer was first calibrated using tungsten-halogen lamp (ASD Inc., Colorado, USA) by illuminating it at an angle of 45° on a white diffuse reflectance standard (WS-1-SL) to obtain reference spectrum. The SpectraSuite software used equation (1) to produce the reflectance spectra:

\[ R_\lambda = \frac{S_\lambda - D_\lambda}{W_\lambda - D_\lambda} \times 100 \]  

where \( R_\lambda \) is the reflectance at the wavelength of \( \lambda \), \( S_\lambda \) is the sample intensity at the wavelength of \( \lambda \), \( D_\lambda \) is the dark intensity at the wavelength of \( \lambda \), and \( W_\lambda \) is the reference intensity at the wavelength of \( \lambda \).

The spectral reflectance was further analysed using spectral gradient where higher spectral gradient indicates better responsivity with smaller change in increasing hue of colour series. This technique is useful in reducing the influence of blue light from white LED itself rather than direct analysis by using raw spectra as raw spectra contain peaks from white LED which are unwanted in colour measurement. Peak wavelengths were also recorded to determine the shift in values due to difference in CCT of light source.

### 3. Results and Discussion

Figure 2 shows white LED spectra obtained when white LEDs were shone onto white diffuse reflectance standard at different illumination angles. Spectra showed that white LEDs used in this study were phosphor-converted white LEDs with combination of blue light and phosphor mixture. D57 had higher blue light composition which made it appear to be more ‘bluish’ compared to D35 which appears to look ‘yellowish-orange’ instead. Illumination angles showed direct influence on the spectral reflectance as 60° gave the highest reflectance followed by 75°, 45°, 30° and 15° for D35 while for D57 a decreasing reflectance order was observed for 60°, 45°, 75°, 30° and 15° respectively. Illumination angle of 75° was found to produce inconsistent results for different white LEDs despite spectral reflectance still being higher than 15° and 30°.

![Figure 2. Spectra of white LED for (a) D35 and (b) D57 under different illumination angles.](image-url)
For blue colour series, the differences in spectral gradient of glossy and non-glossy results are not as significant as in case of green and red. This is due to the influence of blue light of white LED as reflectance measured by spectrometer is the result of interaction between colour paper and lighting which illuminates the samples. It might be a drawback for this type of white LED (phosphor-converted type) to act as light source in observing blue-coloured samples. For green colour series observation, there are peaks observed in spectra between 420 nm to 475 nm which actually are originated from the light sources (Refer figure 2). The overall patterns are discerned and close to the white LEDs spectra demonstrating influence of light sources on reflectance spectra and indirectly on the responsivity of the measured colour.
Conversely, for red colour series, it is noteworthy that the spectral gradients for D35 are higher than for D57 unlike for blue and green colour observations. It can be deduced that D35 which is lower in CCT has improved observation for red colour series and strongly correlated such that warm white LED is a better light source in observing red-coloured samples.

Table 2 shows the peak wavelengths for spectral gradient curve for different illumination angles. The peak wavelengths observed to have similar values despite having different illumination angles for same
type of paper and light source. It shows that illumination angle does not affect colour measurement of
colour papers despite spectral gradient having significant differences such as in green colour series. The
differences in peak wavelengths for same illumination angle and type of paper between lightings also
show that LED CCT does affect colour appearance as measured by spectrometer especially for green
colour series. Peak wavelengths for different types of colour paper under same lighting are compared
next. For green colour series, the difference in values of D35 is smaller (±2 nm) than for D57 (±3 nm)
but results are still acceptable as compared to red colour series results. It is found that the differences
for both D35 and D57 are even bigger (±10 nm for D35 and ±6 nm for D57) indicating surface type of
samples must be the same for measuring red-coloured samples in order to avoid this error.

| Colour Series | Illumination Angles | D35 Glossy | D35 Non-Glossy | D57 Glossy | D57 Non-Glossy |
|---------------|---------------------|------------|---------------|------------|---------------|
| White Diffuse | 15°                 | 444.03     | 440.47        | 445.10     | 440.47        |
|               | 30°                 | 444.74     | 440.47        | 445.10     | 440.47        |
|               | 45°                 | 445.10     | 444.39        | 445.10     | 444.39        |
|               | 60°                 | 445.10     | 444.39        | 445.10     | 444.39        |
|               | 75°                 | 444.39     | 444.39        | 444.39     | 444.39        |
| Blue          | 15°                 | 445.81     | 444.39        | 441.36     | 440.83        |
|               | 30°                 | 445.10     | 445.81        | 441.36     | 440.83        |
|               | 45°                 | 445.10     | 445.81        | 440.83     | 442.96        |
|               | 60°                 | 445.10     | 445.81        | 440.83     | 442.96        |
|               | 75°                 | 445.10     | 445.81        | 440.83     | 442.96        |
| Green         | 15°                 | 537.69     | 539.77        | 531.47     | 534.93        |
|               | 30°                 | 537.69     | 539.77        | 531.47     | 534.93        |
|               | 45°                 | 538.39     | 537.69        | 531.81     | 532.85        |
|               | 60°                 | 538.39     | 539.77        | 532.85     | 534.93        |
|               | 75°                 | 541.15     | 541.15        | 532.85     | 535.62        |
| Red           | 15°                 | 609.40     | 620.17        | 606.03     | 612.77        |
|               | 30°                 | 609.74     | 617.82        | 606.03     | 612.77        |
|               | 45°                 | 609.40     | 617.14        | 606.03     | 609.74        |
|               | 60°                 | 608.39     | 617.82        | 606.03     | 609.74        |
|               | 75°                 | 609.06     | 616.47        | 605.01     | 611.42        |

4. Conclusion
This work showed that illumination angle has direct influence on responsivity of colour measurement
as measured by spectrometer even though peak wavelengths are found to be close to one another. It was
also found that different CCT of white LED as light source does alter the colour measurement of samples
as the peak wavelengths values have significant differences. Further study is required to discover
methods to overcome the variance caused by white LED as light source in spectroscopy measurement.

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