Uncertainty determination of correlated color temperature for high intensity discharge lamps

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Abstract: Color temperature is a description of the color of light sources. The chromaticity coordinates of the light source lying on the Planckian locus which is called (Commission Internationale de l'Eclariage, referred to as CIE) CIE diagram and the source has color temperature (in Kelvin) equal to the blackbody temperature of the Planckian radiator. For light sources that don't have chromaticity coordinates that fall exactly on the Planckian locus but lie near it. In this case the chromaticity coordinates of such sources can be representing by correlated color temperature (CCT). Uncertainty of Correlated Color Temperature (CCT) or **(**T_{cp}**)** for high intensity discharge lamps (HID) is derived from (u, v) color coordinates. The method of the International organization for standardization (ISO) Guide is applied by Gardner to drive analytical expression for uncertainty in **u** and **v** chromaticity coordinates and an uncertainty in CCT for few Kelvins can be achieved. The color temperature standard achieved with the uncertainty is. ± 30 K for mercury lamp, ± 10 K for sodium lamp and ± 29 K for metal halide lamp.

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Key words: lamp, correlated color temperature, Uncertainty and luminous flux.

1. Introduction:

Color temperature is a characteristic of visible light that has important applications in photometry science (calibration and lighting), photography, videography, publishing, manufacturing, and other fields. The color temperature of a light source is the temperature of an ideal black-body radiator that radiates light of the same chromaticity as that light source. The temperature is usually stated in Kelvin (K). It is directly related to Planck's law and Wien's displacement law. The CIE color coordinates are derived by weighting the spectral power distribution (obtained by using a spectroradiometer). the chromaticity coordinates are usually given by normalized coordinates x and y. The (x, y) coordinates are called the chromaticity coordinates. (1) The CCT of a light source, also expressed in Kelvins, is defined as the temperature of the blackbody source that is closest to the chromaticity of the source in this case the CIE 1960 (Uniform Color Space) UCS (*u*, *v*) system is used .(2)

A "modified uniform chromaticity scale diagram" suggested, based on certain simplifying geometrical considerations where (u, v) chromaticity coordinates was used instead of (x,y) . This (u, v) chromaticity space became the CIE 1960 color space, which is still used to calculate the CCT. (3). Higher color temperatures (5,000 K or more) are cool (blueish white) colors, and lower color temperatures (3,000 K or lower) warm (yellowish white through red) colors. For incandescent lamp is called color temperature but for flourescent and high intensity discharge lamps is called Correlated color temperature. (4)

In physics and color science, the Planckian locus is the path or locus that the color of an incandescent black body would take in a particular chromaticity space as the blackbody temperature changes. It goes from deep red at low temperatures through orange, yellowish white,

white, and finally bluish white at very high temperatures. (5)

In this work we have to calculate the uncertainty in u, v and CCT for one high pressure mercury lamp has symbol W1, one high pressure sodium lamp has the symbol W2, and one metal halide lamp has the symbol W3.

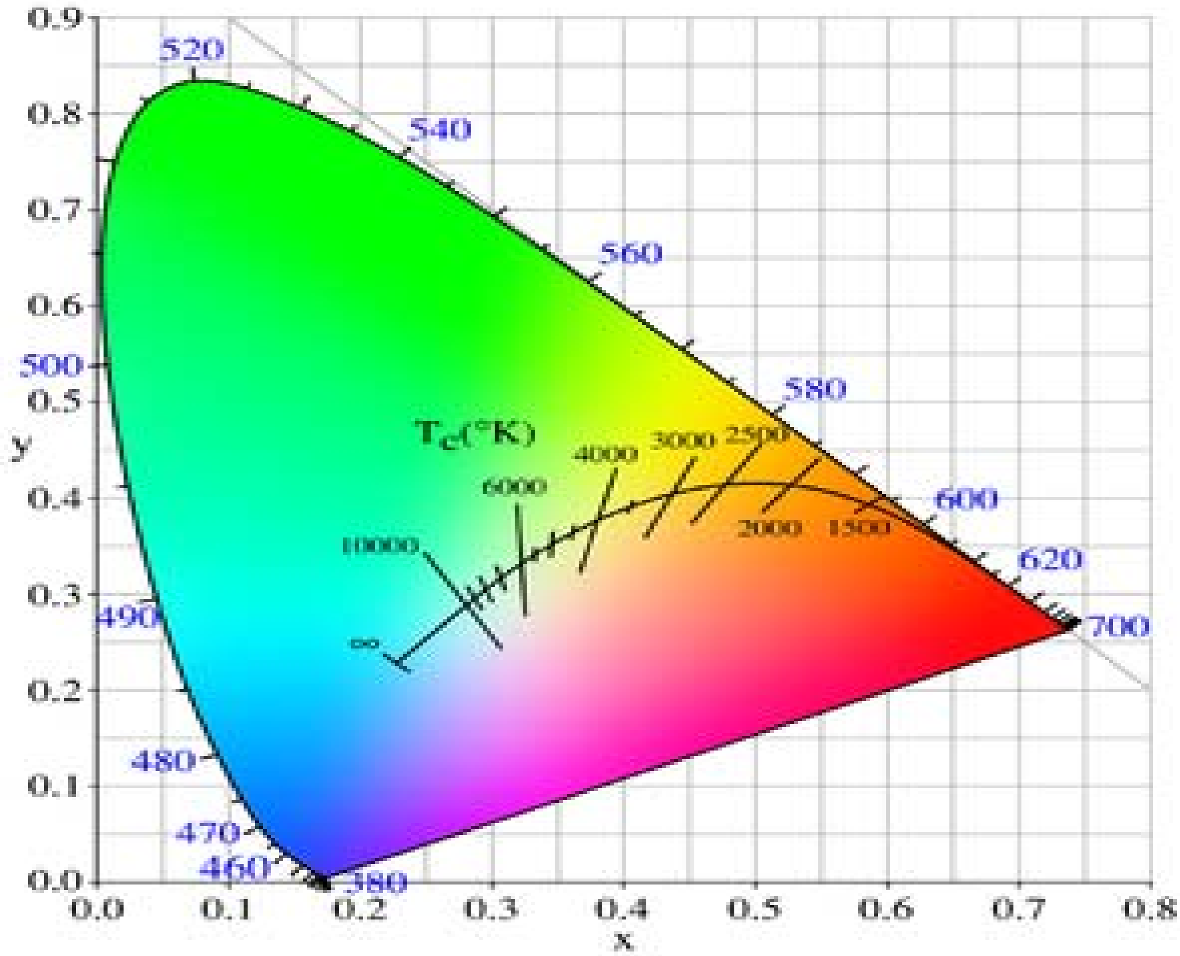

Figure 1.The CIE 1931 x,y chromaticity space, also showing the chromaticities of black-body light sources of various temperatures (Planckian locus), and lines of constant correlated color temperature.

2. The experiment technique

The measurements of CCT and u, v were done by HR 2000 spectroradimeter.

The spectroradiometer system is made up of several elements:

- input optics, (a source or sources, with power supplies and electrical measuring equipment).
- Polychromator (monochromator)/array detector,
- Data acquisition system (electronics for measuring detector output quantity combined with a data processing system).

The spectroradimeter ocean optics HR 2000

Irradiance uncertainty: 4.7%

Figure 2. Spectroradiometer measurements where illuminant A is used to take as reference spectrum borrowed from manual (6) .

In the present work we choose the one lamps of high pressure mercury 125 Watts, one lamp of high pressure sodium 150 watts and one lamp of metal halide 150 watts

Such lamps have CCT from warm (≈ 2200 K) to cool light (≈ 6500 K). In the spectroradimeter measurements irradiance is total radiant flux incident on an element of surface divided by the surface area of elements in W/m^2. (7)

Before any work the lamps should be seasoned until the photometric and electric characteristics remain constant. In the present work the HID lamps must be seasoned for ***100*** operating hours and should be cycled ***11*** hours on and one hour off. The metal halide and high pressure sodium lamps should be stored in the same position as seasoned. (8)

3.Theoretical background

3.1 The uncertainty of (u, v)

The uncertainty in u is

$$u_c(u) = \{ (u-4)^2 \Sigma u_c^2(E_i) x_i^2 + u^2 [225 \Sigma u_c^2(E_i) y_i^2 + 9 \Sigma u_c^2(E_i) z_i^2] + 30u (u-4) \Sigma u_c^2(E_i) x_i y_i + 6u (u-4) \Sigma u_c^2(E_i) x_i z_i + 90 u^2 \Sigma u_c^2(E_i) y_i z_i \}^{1/2} / (\Sigma E_i x_i + 15 \Sigma E_i y_i + 3 \Sigma E_i z_i).$$

And similarly

$$u_c(v) = \{9(5v-2)^2 \ \Sigma\, u_c^2(E_i)\, y_i^2 + v^2 [\Sigma\, u_c^2(E_i)\, x_i^2 + 9\, \Sigma\, u_c^2(E_i)\, z_i^2] + 6v\,(5v-2)\, \Sigma\, u_c^2(E_i)\, x_i\, y_i + 6 v^2\, \Sigma\, u_c^2(E_i)\, x_i\, z_i + 18v\,(5v-2)\, \Sigma\, u_c^2(E_i)\, y_i\, z_i \}^{1/2} / (\Sigma\, E_i\, x_i + 15\, \Sigma\, E_i\, y_i + 3\, \Sigma\, E_i\, z_i) \quad (9)$$

Correlated color temperature CCT:

The CCT of a general source is defined the temperature of the nearest point on the Black-body locus.

The standard uncertainty $u_c(T)$ in CCT is given by

$$u_c(T) = (\partial T/\partial u)^2\, u_c^2(u) + (\partial T/\partial v)^2\, u_c^2(v) + 2r_{uv}\, (\partial T/\partial u)\, (\partial T/\partial v)\, u_c(u)\, u_c(v). \quad (1)$$

Where r_{uv} is the correlation coefficient between u and v and

$\partial T/\partial u = -\,5918.47 + 9.69941\, T - 0.00958899\, T^2 + 1.88114\text{x}10^{-6}\, T^3 - 1.67343\text{x}10^{-10}\, T^4 + 5.42081\text{x}10^{-15}$.

$\partial T/\partial v = -\,385.70 + 8.40689\, T - 0.00362952\, T^2 + 3.71034\, \text{x}10^{-8}\, T^3$.

The correlation coefficient between u and v is given by (1) is

$$r_{uv} = \Sigma\, (\partial u/\partial E_i)\, (\partial v/\partial E_i)\, u_c^2(E_i) \ / \ [\sqrt{\Sigma\, (\partial u/\partial E_i)^2\, u_c^2(E_i)}\ \sqrt{\Sigma\, (\partial v/\partial E_i)^2\, u_c^2(E_i)}] \quad (9)$$

x_i, y_i and z_i are color matching functions (description of a color by the spectral concentration of a radiometric quantity such as radiance or radiant power as a function of wavelength) from 360 nm to 770 nm and obtain from standard table . Radiant power is total emitted by a light source per unit time. (7)

Gardner obtains the uncertainty in CCT derived directly from systematic and random components of the spectral irradiadiance values. (10)

4. Results and discussions:

By setting the lamps at their nominal voltage at distance one meter from input fiber (optics). The u,v and CCT data of each lamp obtained from the computerized spectroradimeter, tabulated in table (1) In table (1) the values of u,v and CCT for each lamp and their uncertainties . Gardner (9) uses this method for calculating CCT for a high pressure sodium lamp reaching uncertainty of CCT for this lamp as 3.1 K assuming an uncertainty of spectral irradiance u_c (E_i) is 0.01 but we measure experimentally the uncertainty of spectral irradiance of spectroradimeter is u_c (E_i) = 4.7% .

Table (1). The values of uncertainty of CCT and u and v obtained by using the spectroradimeter.

lamps	CCT	u	v	$u_c(u)$	$u_c(v)$	r_{uv}	Uc(CCT)	Uc(CCT)%
HPM	6306	0.235	0.326	0.00051	0.00015	-0.321	30	0.48
HPS	2200	0.320	0.361	0.0007	0.00016	-0.415	10	0.45
MH	6036	0.235	0.333	0.00051	0.00014	-0.341	29	0.48

5. Conclusion:

- For the first time in Egypt experimentally determination of the uncertainty of CCT for high intensity discharge lamps.
- By using the uncertainty for CCT we can obtain the uncertainty for mismatch factor, which is very important for calculation of luminous flux uncertainty. budget

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