Uncertainty determination of correlated color temperature for high intensity discharge lamps

A.B. El-Bialy*, M.M. El-Ganainy** and E.M. El-Moghazy***

*University College for Woman for Art, science and education.
** National Institute for Standards (NIS)
*** NIS and Ph.D. student in University College of Woman
emoghazy@yahoo.com

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.

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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)

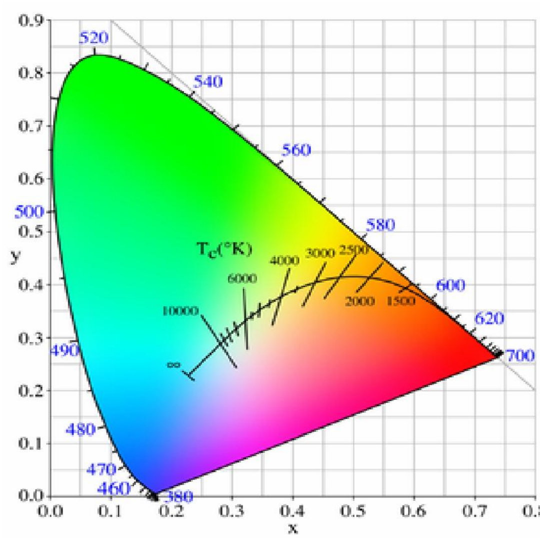

Fig (1). The CIE 1931 x,y chromaticity space, also showing the chromaticities of black-body light sources of various temperatures (Planckian locus), and lines of constant correlated color temperature.

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 lamps has symbol W1, one high pressure sodium lamps has the symbols W2, and one metal halide lamps have the symbols W3.

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:

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

The spectroradimeter has the following Specifications:

1. **Detector**: Sony ILX511 linear CCD array
2. **Detector Range:** 200-1100 nm
3. **Stray Light:** <0.05% at 600 nm; <0.10% at 435 nm
4. **Integration Time (**Time integral of the time resolved measurement): 3 milliseconds to 65 seconds. (6)
5. **Irradiance uncertainty: 4.7%**

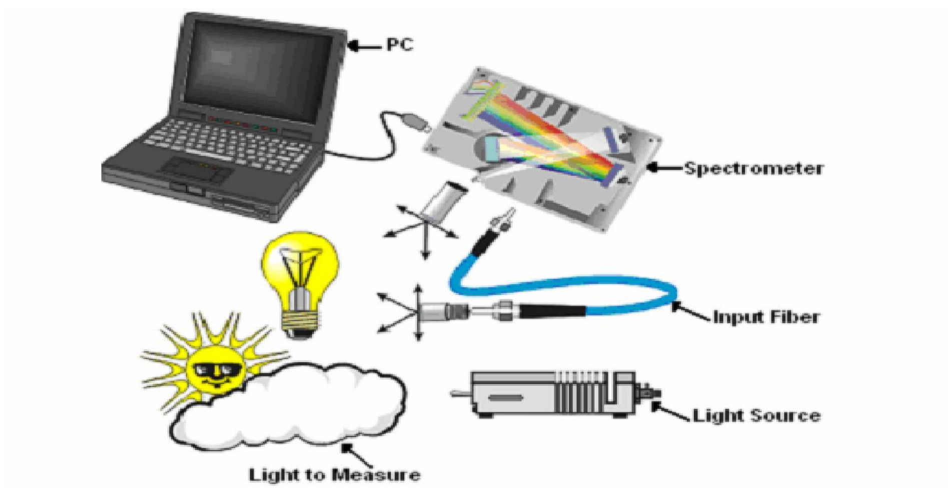

Fig (2). Setup of spectroradiometer measurements where light source is used to take as reference spectrum.

In the present work we choose the one lamps high pressure mercury 125 Watts, one lamps high pressure sodium 150 watts and one lamps 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- The theoretical background:

3-1. The uncertainty of (u,v);

The uncertainty in u is

$$u_c(u) = \{ (u-4)^2 \Sigma u_c^2(E_i) x_i^2 + u^2 [225 \Sigma u_c^2(E_i) y_i^2 + 9 \Sigma u_c^2(E_i) z_i^2] + 30u (u-4)$$

$\Sigma\, u_c^2(E_i)\, x_i\, y_i + 6u\,(u\text{-}4)\, \Sigma\, u_c^2(E_i)\, x_i\, z_i + 90\, u^2\, \Sigma\, u_c^2(E_i)\, y_i\, z_i \}^{1/2} / (\Sigma\, E_i\, x_i + 15\, \Sigma\, E_i\, y_i + 3\, \Sigma\, E_i\, z_i)$.

And similarly

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

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

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

Results and discussions:

By setting the lamps at their nominal voltage and apart one meter from input fiber (optics). The u,v and CCT data of each lamp obtained from the computerized spectroradimeter, tabulated in tables (1-4). In table 1 the values of u,v and CCT for each lamp. In table 2 the values of uncertainty of u,v and their squares. In table 3 we obtained the uncertainty of CCT . Finally in table 4 the values of operating voltage, current and watt for each lamp. We found that photometrically and electrically the W1 is the high uncertainty in CCT for high pressure mercury lamp, the high pressure sodium lamps has lower uncertainty and W3 for metal halide lamps is intermediate . 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 the uncertainty of spectral irradiance $u_c\,(E_i) = 4.7\%$.

Conclusion:

- For the first time in Egypt experimentally determination of the uncertainty of CCT for high intensity discharge lamps.
- The lamps under investigation may use as standard lamps for correlated color temperature.
- By using the uncertainty for CCT we can obtain the uncertainty for mismatch factor, which is very important for calculation of luminous flux uncertainty.

Note:

Commission Internationale de l'Eclariage, referred to as CIE = International Commission on Illumination.

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

Lamps	CCT	u	v
W1	3538	0.236	0.327
W4	2255	0.32	0.361
W7	3657	0.235	0.333

Table (2). The values of uncertainty of u and v and their square

Lamps	∂T/∂u	∂T/∂v	$(\partial T/\partial u)^2$	$(\partial T/\partial v)^2$	Uncertainty of CCT (Kelvin)
W1	-29488.2	-17849.6	8.7E+08	3.2E+08	11.48
W4	-8476.06	-376.64	71843513	141858	3.44
W7	-31058.5	-19833	9.65E+08	3.9E+08	6.4

Table (3). The values of uncertainty of CCT for lamps

Lamps	$u_c(u)$	$u_c(v)$	$u_c^2(u)$	$u_c^2(v)$
W1	0.03	0.018	0.000888	0.000324
W4	0.046	0.018	0.002116	0.00032761
W7	0.015	0.009	0.000228	8.14506E-05

Table (4). The values of Current, volt and power of the lamps

Lamps	Volt (V)	Current (A)	Power (W)
W1	119	1.18	125
W4	91	1.71	133
W7	97	1.87	149

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