Journal of Engineering and Applied Sciences 12 (8): 2054-2057, 2017
ISSN: 1816-949X

Evaluation of Correlated Color Temperature Calculation Methods

Zheleznikova Olga Evgenievna, Prytkov Sergey Vladimirovich and Kokinov Andrei Mikhailovich
Federal State Budget Educational Institution of Higher Education,
"National Research Mordovian State University Named after N.P. Ogarev",
Bolshevistskaya Str.68, 430005 Saransk, Russia

Abstract: The study is devoted to the estimation of absolute errors concerning the methods of Correlated Color Temperature (CCT) calculation using the program developed by the researcher. The graphs of absolute error distribution in the area of CCT determination are presented. According to the obtained results, recommendations are offered on the use of abovementioned methods in the practice of colorimetric measurements. The study also compares the "classical" version of Robertson method which uses 31 isotherms, and the variants with a large number of isotherms. It is shown that an error decreases with a step decrease between isotherms. The calculation program is implemented using Python language and Numpy library, the tables are calculated also using Python language and Scipy library, the graphs are built using Matplotlib library.

Key words: Correlated color temperature, blackbody line, the line of constant correlated temperature, chromaticity coordinates, absolute error

INTRODUCTION

At the end of the sixties of the 20th century, the first methods of CCT calculation appeared. Then about ten methods were proposed (Ohno, 2014; Andres *et al*., 1999; Robertson, 1968). The authors of the methods indicated errors of course but not always an evaluation method. They proposed an analytical method for CCT calculation and absolute errors of CCT calculation methods were presente but the evaluation technique was not presented (Andres *et al*., 1999). That is there is no single approach to the estimation of CCT calculation errors by all existing methods. Therefore, we developed the program for the absolute error calculation concerning CCT methods calculation.

But before the proceeding to the technique description, let's recall that according to Schanda (2007), Ohta and Robertson (2005) and McCamy the correlated color temperature is the temperature of a blackbody with the chromaticity close to the chromaticity spectrum of this spectral distribution on the same contrast MKO diagram of 1960. The concept of a correlated color temperature can not be applied if the distance between the chromaticity of a test source and the black body line is greater than:

$$\Delta C = [(u'_t - u'_p)^2 + 4/9(v'_t - v'_p)]^{1/2} = 5\times10^{-2}$$

where, (u'_t, v'_t) and (u'_p, v'_p) are the chromaticity coordinates of a test source and a black body, respectively on the same contrast MKO diagram of 1974. Isotherm is a line whose all points correspond to the same CCT. Therefore, if we know the temperature which corresponds to the isotherm then taking a point on it and calculating the CCT for it we find an error (both absolute and relative one) of the method at a given point that is in order to estimate an error as CCT real value one should accept isotherm temperature. Besides, based on CCT definition, the error of the method should be determined not at one point but in the band along a blackbody line whose width makes 0.10 (Fig. 1).

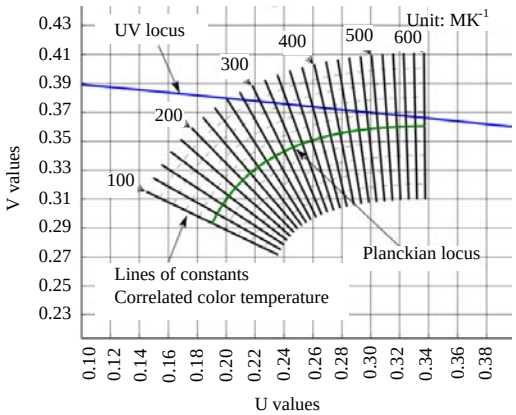

Fig. 1: Blackbody and isotherm line on an equally contrasting MKO chart of 1964

Corresponding Author: Zheleznikova Olga Evgenievna, Federal State Budget Educational Institution of Higher Education, "National Research Mordovian State University Named after N.P. Ogarev", Bolshevistskaya Str. 68, 430005 Saransk, Russia

MATERIALS AND METHODS

Methods: The essence of the methods concerning the estimation of CCT calculation method error is the following one: A table is created during the first stage in which isotherm color coordinates are kept. In this case, Eq. 1 is used:

$$u_1 = u_0 \pm \frac{lv'}{\sqrt{u'^2 + v'^2}}; v_1 = v_0 \pm \frac{lu'}{\sqrt{u'^2 + v'^2}} \quad (1)$$

Where:

u' = du/dt

v' = dv/dt

u_0, v_0 = Chromaticity coordinates of a black body

l = The distance between the line of a black body and a curve parallel to it

Note that we used numerical differentiation to find u' and v'. The isotherm calculation procedure is described in detail by Prytkov then the second table is developed, the cells of which keep CCT calculation results for the chromaticities from the first. Table is developed at the third stage, the cells of which keep an absolute error. During an error calculation the temperature of isotherms is taken for an actual value.

So, the essence of the technique is to use isotherm coordinates as the input data and to determine the absolute error as the difference between the calculated CCT value and the temperature of the isotherm. Figure 2 illustrates the algorithm described above.

The use of reverse Mega-Kelvin MK^{-1} as the unit of temperature measurement is related to the fact that on an equal-contrast chart the chosen temperature step (for example, ΔT = 20 MK^{-1}) will correspond to approximately the same number of color detection thresholds that is the distance between isotherms will be the same one.

Main part: Robertson's method for CCT calculation was proposed in 1968 (Robertson, 1968; Wyszecki and Walter, 1967). It had a wide practical application and has not lost its relevance still. For example in the software of modern spectroradiometers this method is often realized, the essence of which is in the linear interpolation of isotherms.

An original method is based on the calculation Table 1 describing the properties of 31 isotherms (from 10-660 MK^{-1} with a step of 10 MK^{-1}). We have reduced the distance between isotherms. Thus, Tables were calculated for the step 5 of 2.5 and 1 MK^{-1}.

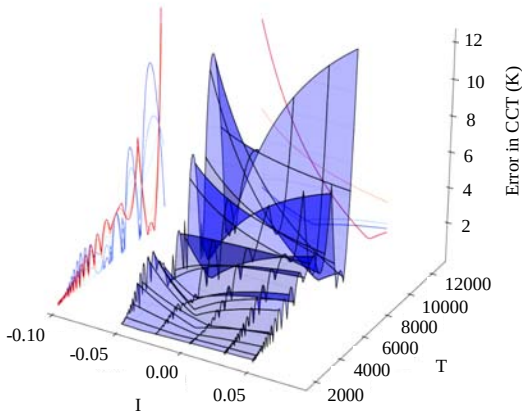

Fig. 2: Graph of Robertson's method absolute error for the table by Vyshetski G. Wyszecki

Table 1: Absolute error of Robertson's method

Errors in CCT (K)			
10 MK^{-1}	5 MK^{-1}	2.5 MK^{-1}	1 MK^{-1}
12.4	0.6	0.16	0.025

The results of CCT calculation error estimation by this method are given in Table 1, the analysis of which may bring to the conclusion that the error decreases with a step decrease. And with a step of 1 MK^{-1} on a practically important temperature range from 1667-10000 K, the error of the method is close to 0.

Figure 2 illustrates the distribution of an absolute error in the range of 1667-10000 K for the table proposed by Wyszecki. It shows the temperature along the abscissa axis, the distance from the black body line along the ordinate axis and the absolute error along the applicate axis. Figure 2 graph of Robertson's method absolute error for the table by Wyszeckiand Walter (1967) according to Fig. 2, the error increases with the temperature increase. McKamy method was proposed in 1992. The third order polynomial is proposed for CCT calculation. The polynomial was obtained on the assumption that all isotherms intersect at a certain point on the XYZ chromaticity diagram.

The estimate of CCT calculation error by this method shown in Fig. 3 that it is significantly inferior to Robertson's method in accuracy. The maximum error within 1700-10000 K range was 285.4 K. Havier Hernandez method was proposed in 1999 (Andres *et al*., 1999). Like McKamy method, it has an analytical solution. The estimate of CCT calculation error by this method made it possible to state (Fig. 4) that it is also much inferior to Robertson's method in accuracy. The maximum error within the range of 1700-10000 K was 429.4 K.

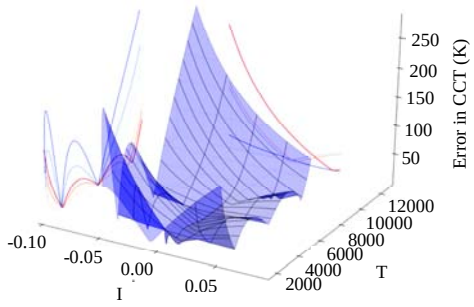

Fig. 3: The graph of McKamy method absolute error in the range of 1700-10000 K

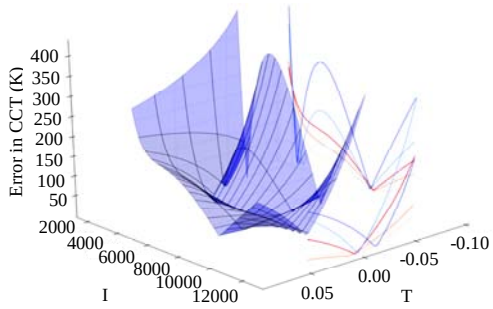

Fig. 4: The graph of CCT calculation absolute error by Havier Hernandez method within the range of 1700-10000 K

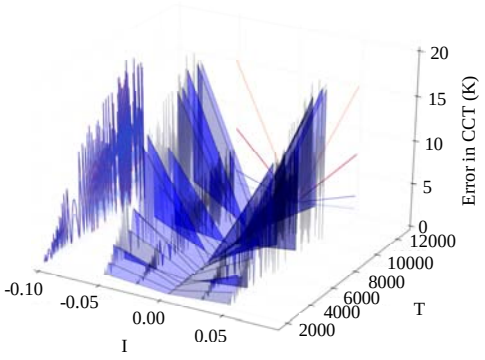

Fig. 5: Absolute error graph during CCT calculation by the method of triangles in the range of 1700-10000 K

In 2013 Yoshi Ono proposed three methods for CCT calculation: the triangle method, the parabola method and the combined method (Andres *et al*., 1999). All of them are based on the same calculation table. Table 2 shows the absolute errors of CCT calculation by Yoshi Ono methods. Figure 5-7 show the graphs of absolute error distribution for the corresponding CCT calculation methods.

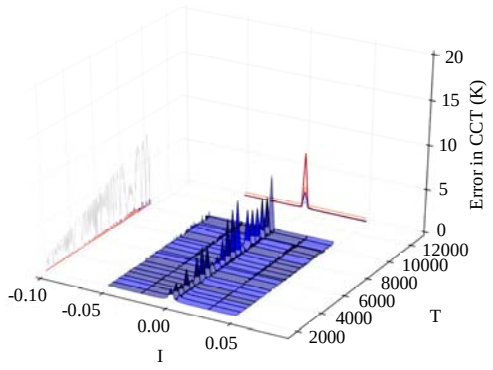

Fig. 6: Absolute error graph during CCT calculation by parabolic method in the range of 1700-10000 K

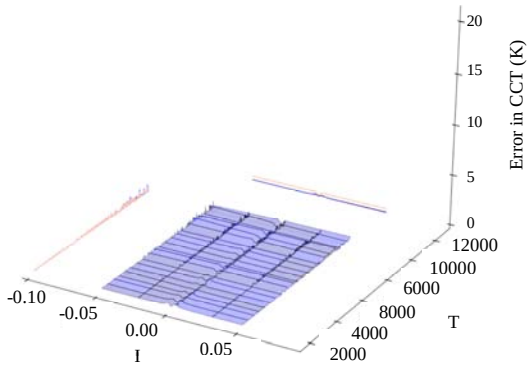

Fig. 7: Absolute error graph during CCT calculation by combined method in the range of 1700-10000 K

Table 2: Absolute errors of CCT calculation by Yoshi Ono methods

	Errors in CCT (K)
Methods	1667-10000 K
Triangular	19.1
Parabolic	8.5
Combined	0.9

Summary: CCT calculation methods are described in the study: Robertson (1968), Camy (1992), Havier Hernandez and Yoshi Ono error was estimated using the program developed by the researchers.

CONCLUSION

Thus, the research performed research determined the following: The error of CCT calculation increases with temperature increase for Robertso's method. With the calculated table step of 1 μ in the temperature range of

1700-10000 K, the error of the method is close to 0; an absolute error does not exceed 19.1 K for Yoshi Ono method of triangles in the temperature range 1667-10000 K. The method of parabolas on the same section is more accurate and an absolute error for it does not exceed 8.5 K. The combined method has the highest accuracy. The absolute error makes 0.9 at the section 1667-10000 K; for McCamy method, the error in the area of 1700-10000 K reaches 250 K. The error for the McCamy method strongly depends on the location in the band along a blackbody line. As a rule, the minimal error for CCT calculation by McCamy method is observed near a blackbody; for the Havier Hernandez method, the error in the area of 1700-10000K reaches 429.4 K. As in the case of the previous method, the error depends strongly on the location in the band along a blackbody line.

RECOMMENDATIONS

The combined Yoshi Ono method is recommended by us as the most optimal method to calculate an absolute CCT error in terms of accuracy.

REFERENCES

Andres, H.J., R.L. Lee and J. Romero, 1999. Calculating correlated color temperatures across the entire gamut of daylight and skylight chromaticities. Appl. Opt., 38: 5703-5709.

Camy, M.C.S., 1992. Correlated color temperature as an explicit function of chromaticity coordinates. Color Res. Appl., 17: 142-144.

Ohno, Y., 2014. Practical use and calculation of CCT and Duv. Illum. Eng. Soc., 10: 47-55.

Ohta, N. and A.R. Robertson, 2005. Colorimetry: Fundamentals and Applications. University of Virginia, Charlottesville, Virginia, ISBN: 9780470094723, Pages: 334.

Robertson, A.R., 1968. Computation of correlated color temperature and distribution temperature. J. Opt. Soc. Am., 58: 1528-1535.

Schanda, J., 2007. Colorimetry: Understanding the CIE System. John Wiley & Sons, Hoboken, New Jersey, USA., ISBN: 978-0-470-04904-4, Pages: 453.

Wyszecki, G. and S.S. Walter, 1967. Color Science: Concepts and Methods, Quantitative Data and Formulae. University of Michigan University, Ann Arbor, Michigan, Pages: 628.