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Effectiveness of an alternative model for establishing mesopic luminance

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Short title: An alternative model for mesopic luminance

To determine mesopic luminance for a given photopic luminance and S/P ratio, the International Commission on Illumination (CIE) recommended system utilizes an equation. Whilst being accurate, it requires several iterations to achieve a stable result and requires use of an adaptation coefficient (m). This article proposes an alternative approach, a model developed using a Rational Taylor function which does not require either iteration or an adaptation coefficient. Road lighting tends to use average photopic luminances in the range of 0.1 to 3 cd/m^2: within this range, the model has an average error of 0.28% against the iteration approach, which is sufficient for most practical purposes.

1 Introduction

Visual conditions under road lighting tend to fall within the mesopic range, photopic luminances of 0.005 to 5 cd/m^2 [1]. In this region, the visual system exhibits a spectral sensitivity that lies between the photopic [2,3] and scotopic [4-7] ranges according to the state of visual adaptation. It is useful for road lighting designers to know the spectral response of vision in the mesopic range because it may influence their choice of lamp and analyses of energy efficiency. This need was solved in 2010 when the CIE [1] recommended a system of mesopic photometry.

For a given photopic luminance, determination of mesopic luminance requires knowledge of the ratio of scotopic and photopic luminances (S/P ratio).[1] For example, consider a high-pressure sodium lamp (HPS) of S/P ratio = 0.65 at a photopic luminance of 0.3 cd/m^2; the corresponding mesopic luminance is 0.2764 cd/m^2. The mesopic enhancement factor (F_{mes}), the quotient of the mesopic and photopic adaptation luminances, is 0.9213 for this same example.

The CIE describe two approaches that may be used to establish mesopic luminance. The first (the iteration approach) is to use equations (1- 2), here L_p is the photopic adaptation luminance, L_s is the scotopic luminance, $V'(\lambda_0)$ = 683/1699 is the value of scotopic spectral luminous efficiency function at λ_0 = 555 nm, $L_{mes,n}$ is the mesopic luminance, m is the adaptation coefficient, n it the iteration step, and a and b are coefficients equal to 0.7670 and 0.3334, respectively. This is labelled MES2 in the CIE system.[1] This approach requires knowledge of the photopic and scotopic luminances, which can be calculated if the spectral power distribution of the source is known. Initially, equation (1) is applied with the assumption that m_0 has the value of 0.5. The resulting value of $L_{mes,n}$ is then substituted into equation (2) to determine a revised value of m, which is in turn substituted back into equation (1). This process is repeated until a stable L_{mes} is achieved. Typically, four to ten iterations are required which makes it inconvenient in application. It is however recognized as giving the accurate outcome and can be applied to any combination of photopic luminance and S/P ratio.

$$L_{mes,n} = \frac{m_{(n-1)}L_p + (1-m_{(n-1)})L_s V'(\lambda_0)}{m_{(n-1)} + (1-m_{(n-1)})V'(\lambda_0)} \tag{1}$$

$$m_n = a + b\log_{10}(L_{mes,n}) \quad \text{for } 0 \le m \le 1 \tag{2}$$

The second approach is to use the CIE look-up table (Table A.1b in the literature[1]). This table reports mesopic luminance as a function of photopic luminance and S/P ratio, for photopic luminances of 0.01, 0.03, 0.1, 0.3, 1.0, 3.0 and 4.5 cd/m^2, and for S/P ratios between 0.25 and 2.75 at intervals of 0.1. These values were determined, by the CIE, using the iteration approach. Where these values are appropriate to the application, the look-up table approach is clearly the easier to use. However, to establish mesopic luminance for intermediate values of photopic luminance (and/or intermediate values of S/P ratio) then there is a need for linear interpolation. Using interpolation with the CIE table provides a relatively simple way to establish mesopic luminance, but this process leads to mesopic luminances which are not consistent with those determined using iteration, the more precise approach (see section 4).

In summary, the iteration approach to estimating mesopic luminance provides precise estimates but is less convenient for practical application; the look-up table is more convenient, but the requirement for interpolation may lead to error. This article describes an alternative method, a mathematical model which results in the same mesopic luminances as determined using the iteration approach. The iterative approach is used as the reference against which the model is compared. While some studies have pointed out errors in the iteration approach, [8,9] these tend to concern very high S/P ratios or low luminances that are not of practical significance.

2 The functional modelling of mesopic luminance

As a first step in developing an alternative model, the scotopic luminance (L_s) term of the CIE equation (1) was replaced by the product of photopic luminance (L_p) and S/P ratio (R_{sp}) (equation (3)).

$$L_{mes,n} = \frac{m_{(n-1)}L_p + (1 - m_{(n-1)})L_p R_{sp} V^{'}(\lambda_0)}{m_{(n-1)} + (1 - m_{(n-1)})V^{'}(\lambda_0)} \tag{3}$$

As shown by equation (3), the relation between L_{mes} and L_p, or between L_{mes} and the S/P ratio, is not linear, and hence by inference, nor is the contour map of L_{mes} as a function of

L_p and R_{sp} a simple plane function. It is therefore not appropriate to use a plane fitting function to fit L_{mes}. The model was developed to overcome the need for iteration and to reach a high degree of accuracy (i.e. to provide the same solutions as equation (1)) and for this we proposed to fit the data to a Rational Taylor function [10,11] as shown in Equation (4). In equation (4), L_{mes} is the mesopic luminance in cd/m^2, L_p is the photopic luminance in cd/m^2, z_0, A_{01}, B_{01}, B_{02}, C_{02}, A_1, A_2, B_1, B_2 and C_2 are coefficients.

$$L_{mes} = \frac{z_0 + A_{01}R_{sp} + B_{01}L_p + B_{02}{L_p}^2 + C_{02}R_{sp}L_p}{1 + A_1R_{sp} + B_1L_p + A_2{R_{sp}}^2 + B_2{L_p}^2 + C_2R_{sp}L_p} \qquad (4)$$

The fitting was initially applied across a broad section of the mesopic luminance range [photopic luminances of 0.01 to 4.5 cd/m^2]. Figure 1 shows mesopic luminances as a function of photopic luminance and S/P ratio. This was determined by two approaches: first, the values as given in the CIE look-up table, and second as calculated using Equation (4) with best-fit coefficients. As shown in Figure 1, equation (4) works well at high luminances, but there is a discrepancy at low luminance, especially at photopic luminances below 0.1 cd/m^2.

To address this problem, the luminance range was divided into two parts: range A, from photopic luminances of 0.01 to 0.1 cd/m^2, and range B, from 0.1 to 4.5 cd/m^2. Equation (4) was fitted separately to these two ranges, and the optimal coefficients are shown in Table 1. Within both ranges, these coefficients lead to mesopic luminances which match those determined using the iteration approach (coefficient of determination, R^2=1.00) (Figure 2).

The effectiveness of this model (equation (4) with coefficients shown in Table 1) was investigated by calculating relative error, the difference between this approach and the corresponding mesopic luminance obtained from the iterative approach. Figure 3 show the error (%) between the model and iterative approach, with coefficients for ranges A and B used in their respective ranges of photopic luminance. The border between ranges A and B lies at a photopic luminance of 0.1 cd/m^2, and hence at this point mesopic luminance were calculated using both versions of the equation. Figure 3 shows that a small error is introduced when using range B at 0.1 cd/m^2 and hence that range A is preferable.

Relative error tends to be less than 1% across a wide range of photopic luminances and S/P ratios, but increases to a larger error (2% to 8%) for combinations of very low S/P ratio (< 0.5) and very low luminance (< 0.03 cd/m^2). Few light sources have an S/P ratio of 0.5 or less and therefore these errors are not of practical importance. For most road lighting scenes, the photopic luminances are likely fall in to the range of 0.01 to 3 cd/m^2, [12] and in this region the new model provides results of sufficient accuracy for practical purposes (average error 0.28%).

3 Calculation of adaptation coefficient m and error analysis

According to CIE 191:2010,[1] the relationship between adaptation coefficient m and L_{mes} can be expressed as shown in equation (5).

$$m = a + b\log_{10} L_{mes} \text{ for } 0 \le m \le 1. \quad (5)$$

By substituting the new model for L_{mes} (equation (4)) into equation (5), the adaptation coefficient m can be expressed as a function of L_p and R_{sp} as shown in equation (6). The coefficients are as shown in Table 1: range B would be applied for photopic luminances ≥ 0.1 cd/m^2, and range A for luminances < 0.1 cd/m^2.

$$m = a + b\log_{10}\left(\frac{z_0 + A_{01}R_{sp} + B_{01}L_p + B_{02}L_p{}^2 + C_{02}R_{sp}L_p}{1 + A_1R_{sp} + B_1L_p + A_2R_{sp}{}^2 + B_2L_p{}^2 + C_2R_{sp}L_p}\right). \quad (6)$$

Figure 4 shows contours of adaptation coefficient m as a function of photopic luminance and S/P ratio. The coefficient contours were determined using two methods. First, using the values reported by CIE (Table A.1a [1]), and second, for the same values of photopic luminance and S/P ratio, using equation (6). Over the broad range of conditions equation (6) matches the adaptation coefficient reported by CIE: it is only in the region of low photopic luminances (<0.05 cd/m^2) and low S/P ratio (<0.75) that there are differences.

These differences are shown in Figure 5, which plots the relative error between the calculated (equation (6)) and CIE given[1] values of adaptation coefficient m. For the majority of this space, the relative error is less than 1%. In the region of S/P ratios ranging from 0.25 to 0.5 and photopic luminances ranging from 0.1 to 0.3 cd/m^2 the relative error is larger (from 2%-16%) but since only few light sources have such a small values of S/P ratio, then the error is not of practical importance.

4 Effectiveness analysis of different approaches

Tables 2, 3 and 4 show mesopic luminances determined using the three approaches – iteration, the proposed model and linear interpolation. This was done for seven photopic luminances, of which four (0.1, 0.3, 1.0 and 3.0 cd/m^2), are the reference values of the CIE look-up table, and the remaining three (0.1732, 0.5477 and 1.7321 cd/m^2) are intermediate between these. For these seven photopic luminances, mesopic luminances were determined for the whole range of S/P ratios included in the CIE look-up table. In Table 2, all mesopic luminances were determined using the iteration approach. Table 3 shows mesopic luminances determined using the proposed model, and for this range of photopic luminances the range B coefficients were used (Table 1). In Table 4, mesopic luminances for photopic luminance levels 0.1, 0.3, 1 and 3 cd/m^2 are those as reported in the CIE table: the intermediate values were determined by linear interpolation.

The new model was fitted to the values of mesopic luminance reported by CIE in the look-up table, i.e. for photopic luminances of 0.01, 0.03, 0.1, 0.3, 1.0, 3.0 and 4.5 cd/m^2. The analyses in sections 2 and 3 show that, for these values, the new model is accurate. We next consider how well the proposed model predicts other values, i.e. the mesopic luminances corresponding to intermediate values of photopic luminance (0.1732, 0.5477, and 1.7321 cd/m^2). First consider the accuracy of values determined by interpolation against those determined by iteration. Comparing Tables 2 and 4, the average error is 15.64%. Next consider the accuracy of values determined by the proposed model against those determined by iteration. Comparing Tables 2 and 3, the average error is 0.31%. For these values of photopic luminance, the proposed model provides a more accurate prediction of mesopic luminance than does interpolation within the CIE look-up table.

5 Application

In application, the proposed model offers an alternative to determination of mesopic luminance than the CIE iteration method. In both cases, it is assumed that the photopic luminance and lamp S/P ratio are known.

For a given S/P ratio, the CIE system requires an iterative approach for transforming from photopic to mesopic luminance. [13]

1. Determine the photopic adaptation luminance, $L_{v,adapt}$, by averaging luminances in the adaptation field of the given luminance distribution.
2. Determine the scotopic adaptation luminance, $L'_{v,adapt}$, by multiplying $L_{v,adapt}$ by R_{SP}.
3. Calculate the mesopic adaptation luminance, $L_{mes,adapt}$, and the adaptation coefficient, m, from the photopic/scotopic adaptation luminances per iterative steps of equations (4) and (5) in CIE 191:2010 (equations (1-2) in this work). Alternatively, these may also be determined from look-up tables A.1a and A.1b in the CIE 191:2010 Appendix.
4. Calculate the mesopic enhancement factor $F_{mes}(L_{v,adapt}; R_{SP})$, which is defined as the quotient of the mesopic adaptation luminance and the photopic adaptation luminance. To convert the photopic luminance at each point in the lighting design/installation to the mesopic luminance, multiply the photopic luminance at the point by the mesopic enhancement factor.

Application of the new model is a simpler procedure, specifically, steps 2 and 3 are simplified and the first and final steps are identical:

1. Determine the photopic adaptation luminance, $L_{v,adapt}$, by averaging luminances in the adaptation field of the given luminance distribution.
2. Calculate $L_{mes,adapt}$ using equation (4) with specific values of $L_{v,adapt}$ and R_{SP}, and calculate the adaptation coefficient m using equation (5).
3. Calculate the mesopic enhancement factor F_{mes} $(L_{v,adapt}; R_{SP})$, which is defined as the quotient of the mesopic adaptation luminance and the photopic adaptation luminance. To convert the photopic luminance at each point in the lighting

design/installation to the mesopic luminance, multiply the photopic luminance at the point by the mesopic enhancement factor.

Note that while adaptation coefficient *m* can be calculated using the new model (step 2), this is no longer necessary in the determination of L_{mes}.

6 Conclusion

The CIE has recently recommended a system for establishing mesopic luminances. [1,13] For any combination of photopic luminance and S/P ratio the mesopic luminance can be determined with accuracy using the CIE iteration approach: whilst being accurate, the need for iteration means it may not always be convenient. As an alternative, the CIE also offers a look-up table which provides mesopic luminances, determined using iteration for a sample of photopic luminances and S/P ratios: for intermediate values, interpolation is required, and we show here that this interpolation introduces some error (an average error of 15.64% for the values considered here).

This article described an alternative approach, a Rational Taylor model fitted to the mesopic luminances shown in the CIE look-up table. Across the mesopic range, this required the use of two sets of coefficients (range A, from photopic luminances of 0.01 to 0.1 cd/m^2, and range B, from 0.1 to 4.5 cd/m^2), but for the conditions typical of road lighting then only one of these is required, range B. Within range B, the average error when using the proposed model rather than the iterative approach is only 0.28%. The proposed model is also more accurate than interpolation within the look-up table.

The new model therefore offers two advantages compared with the approaches recommended by CIE. First, it is more convenient than the iterative approach since it does not require iteration and does not require computation of the adaptation coefficient. Second, it leads to mesopic luminances which match those determined by iteration, and has less error than does interpolation. The alternative model also leads to shorter computation time (for 1 million S/P ratios, approx. 7 ms versus 140 ms for the 3-iteration approach): although this difference is largely trivial for most current applications, it may become relevant in the move toward big data analyses.

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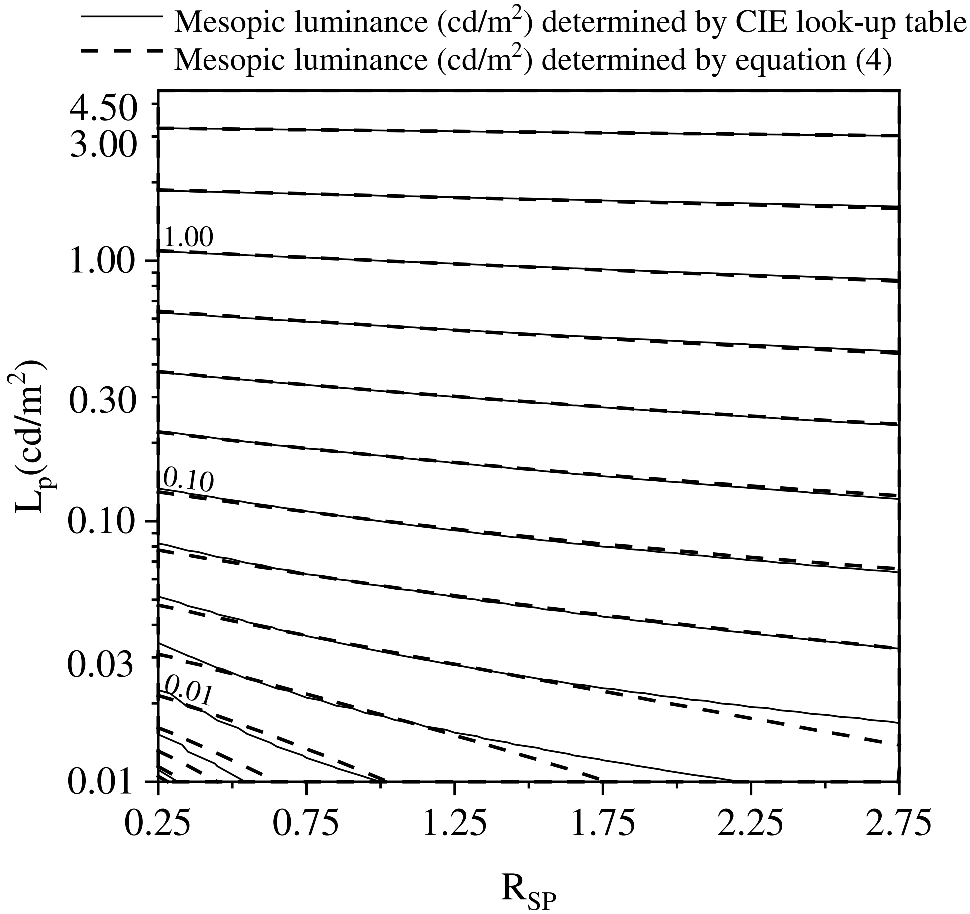

Figure 1. Contour map of mesopic luminance as a function of photopic luminance and S/P ratio (R_{sp}). The legend shows mesopic luminances as determined using the CIE mesopic look-up table (L_{mes}, Table A.1b[1]). The dashed lines show contours of mesopic luminance as determined using equation (4) with coefficients fitted to the whole range of photopic luminances. The photopic and mesopic luminance scales use logarithmic progression. The mesopic luminance contour lines range from 0.0056 cd/m^2 to 3.1623 cd/m^2 with an interval of 0.25 log unit.

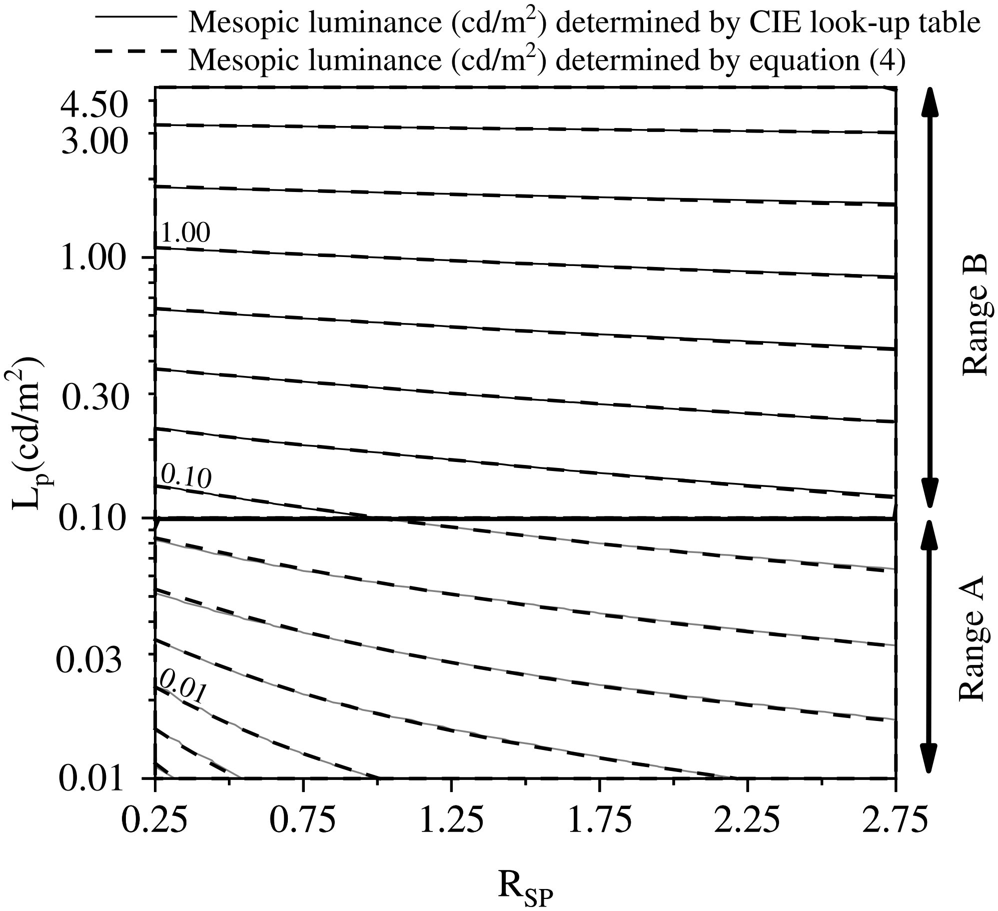

Figure 2. Contour map of mesopic luminance as a function of photopic luminance and S/P ratio (R_{sp}). The legend shows mesopic luminances as determined using the CIE mesopic look-up table (L_{mes}, Table A.1b) ([1]). The dashed lines show contours of mesopic luminance as determined using equation (4) with coefficients determined separately for the two ranges of photopic luminance (Table 1). The photopic and mesopic luminance scales use logarithmic progression.

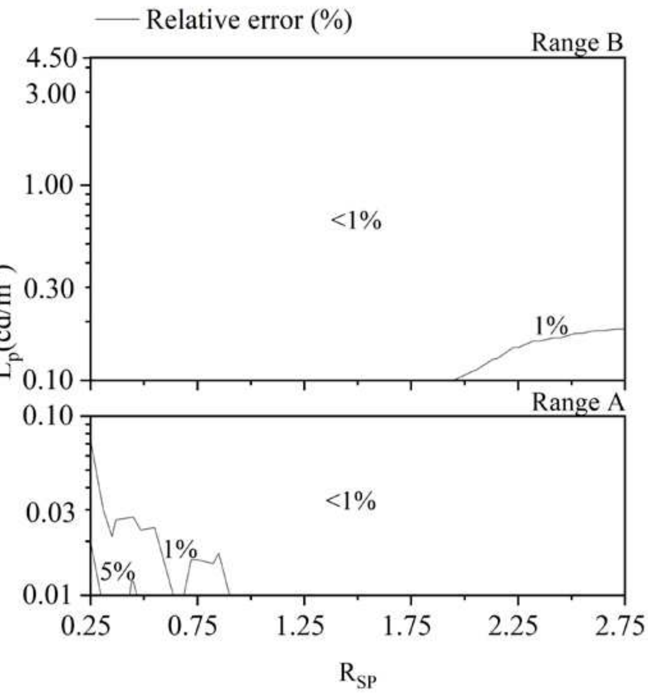

Figure 3. Relative error in photopic luminance as estimated using the proposed model compared with the iterative approach. The contour map shows a relative difference in percent. This was done using the coefficients (Table 1) for range A (bottom) and range B (top).

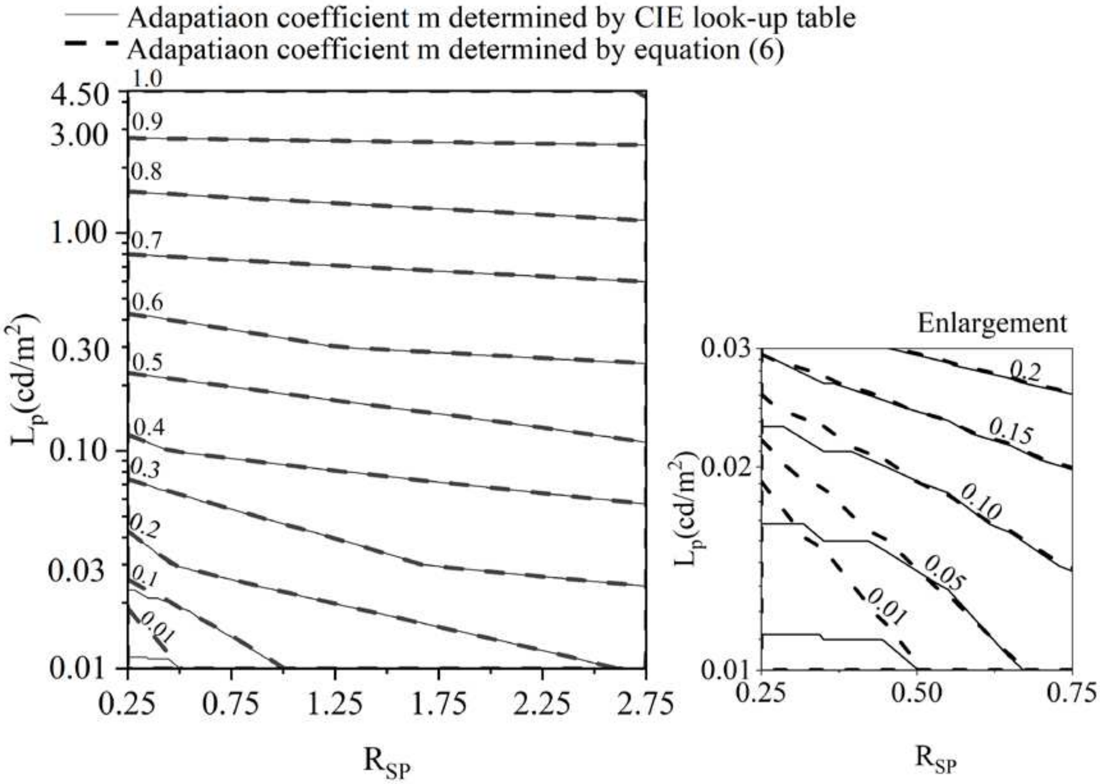

Figure 4. Contours of adaptation coefficient m as a function on photopic luminance and S/P ratio. The legend shows mesopic adaptation coefficient as determined using the CIE mesopic look-up table (Table A.1a[1]). The dashed lines show contours of mesopic adaptation coefficient m as determined using equation (6) with coefficients as shown in Table 1. The graphs show a broad range of photopic luminances (left) and an expansion of the region where there is some error (right).

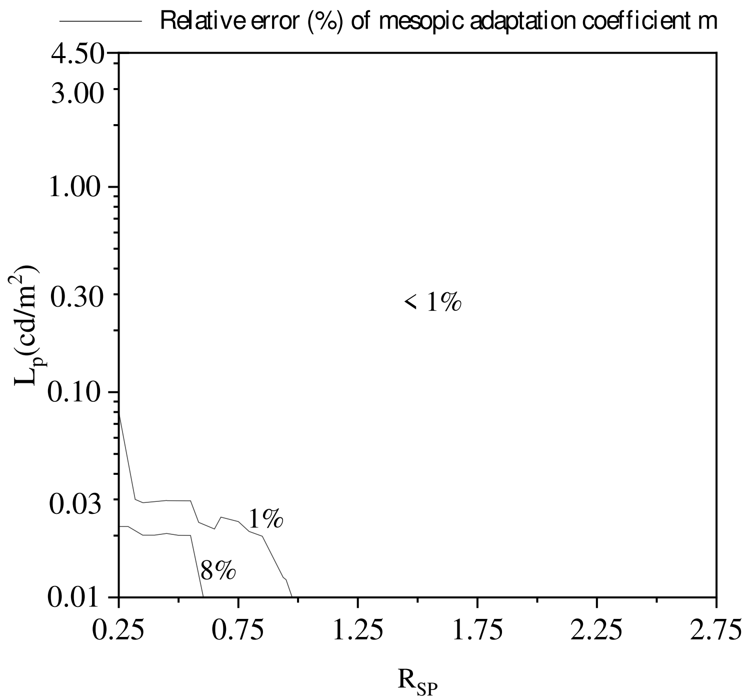

Figure 5. The error analysis using new model comparing to CIE mesopic adaptation coefficient *m* data. The contour map shows a relative difference in percent.

Table 1. Coefficients of the Rational Taylor function (equation (4)) in photopic luminance ranges A and B.

Coefficient	**Range A** [0.01 to 0.1 cd/m^2]	**Range B** [0.1 to 4.5 cd/m^2]
z_0	-0.00477	-0.02097
A_{01}	0.00411	0.02051
B_{01}	0.22525	0.78873
B_{02}	9.86481	0.60472
C_{02}	1.35947	0.31158
A_1	0.55473	0.10154
A_2	-0.04891	-0.00085
B_1	11.73275	0.56106
B_2	-17.54381	0.00017
C_2	0.58998	0.04284

Table 2. Mesopic luminances determined using the iteration approach.

R_{sp}	Photopic luminance (cd/m^2)						
	0.1	**0.1732**	**0.3**	**0.5477**	**1**	**1.7321**	**3**
0.25	0.0705	0.1333	0.2467	0.4772	0.9130	1.6388	2.9265
0.35	0.0705	0.1333	0.2467	0.4772	0.9130	1.6387	2.9265
0.45	0.0750	0.1392	0.2545	0.4873	0.9253	1.6518	2.9367
0.55	0.0793	0.1449	0.2620	0.4971	0.9373	1.6647	2.9468
0.65	0.0834	0.1504	0.2693	0.5068	0.9492	1.6773	2.9568
0.75	0.0873	0.1557	0.2764	0.5162	0.9608	1.6898	2.9666
0.85	0.0911	0.1609	0.2833	0.5254	0.9722	1.7021	2.9763
0.95	0.0947	0.1659	0.2901	0.5345	0.9835	1.7142	2.9859
1.05	0.0983	0.1708	0.2967	0.5433	0.9945	1.7261	2.9953
1.15	0.1017	0.1756	0.3032	0.5521	1.0054	1.7379	3.0046
1.25	0.1051	0.1803	0.3096	0.5606	1.0161	1.7495	3.0139
1.35	0.1083	0.1848	0.3158	0.5691	1.0267	1.7610	3.0230
1.45	0.1115	0.1893	0.3220	0.5773	1.0371	1.7722	3.0319
1.55	0.1147	0.1937	0.3280	0.5855	1.0473	1.7834	3.0408
1.65	0.1178	0.1981	0.3339	0.5935	1.0575	1.7944	3.0496
1.75	0.1208	0.2023	0.3398	0.6015	1.0674	1.8052	3.0582
1.85	0.1238	0.2065	0.3455	0.6093	1.0773	1.8160	3.0668
1.95	0.1267	0.2106	0.3512	0.6170	1.0870	1.8266	3.0753
2.05	0.1295	0.2147	0.3568	0.6246	1.0966	1.8370	3.0836
2.15	0.1324	0.2186	0.3623	0.6320	1.1060	1.8474	3.0919
2.25	0.1352	0.2226	0.3677	0.6394	1.1154	1.8576	3.1001
2.35	0.1379	0.2265	0.3731	0.6468	1.1246	1.8677	3.1082
2.45	0.1406	0.2303	0.3784	0.6540	1.1338	1.8777	3.1162
2.55	0.1433	0.2341	0.3836	0.6611	1.1428	1.8875	3.1241
2.65	0.1459	0.2378	0.3888	0.6682	1.1517	1.8973	3.1319
2.75	0.1485	0.2415	0.3939	0.6751	1.1605	1.9070	3.1396

Table 3. Mesopic luminances determined using the proposed model (range B)

R_{sp}	Photopic luminance (cd/m^2)						
	0.1	**0.1732**	**0.3**	**0.5477**	**1**	**1.7321**	**3**
0.25	0.0710	0.1355	0.2495	0.4783	0.9112	1.6364	2.9270
0.35	0.0751	0.1408	0.2565	0.4881	0.9237	1.6499	2.9373
0.45	0.0790	0.1460	0.2635	0.4976	0.9360	1.6631	2.9474
0.55	0.0829	0.1511	0.2703	0.5070	0.9480	1.6761	2.9573
0.65	0.0867	0.1560	0.2770	0.5163	0.9599	1.6889	2.9671
0.75	0.0905	0.1609	0.2836	0.5254	0.9715	1.7016	2.9768
0.85	0.0942	0.1657	0.2901	0.5343	0.9830	1.7140	2.9863
0.95	0.0978	0.1705	0.2965	0.5431	0.9943	1.7262	2.9957
1.05	0.1013	0.1751	0.3027	0.5517	1.0054	1.7383	3.0050
1.15	0.1048	0.1797	0.3089	0.5602	1.0164	1.7501	3.0141
1.25	0.1083	0.1841	0.3149	0.5686	1.0271	1.7618	3.0232
1.35	0.1117	0.1886	0.3209	0.5768	1.0377	1.7733	3.0321
1.45	0.1150	0.1929	0.3267	0.5849	1.0482	1.7847	3.0408
1.55	0.1182	0.1972	0.3325	0.5929	1.0585	1.7959	3.0495
1.65	0.1215	0.2014	0.3382	0.6007	1.0686	1.8069	3.0581
1.75	0.1246	0.2055	0.3438	0.6085	1.0786	1.8178	3.0665
1.85	0.1277	0.2096	0.3493	0.6161	1.0884	1.8286	3.0749
1.95	0.1308	0.2136	0.3547	0.6236	1.0981	1.8391	3.0831
2.05	0.1338	0.2175	0.3600	0.6310	1.1077	1.8496	3.0912
2.15	0.1368	0.2214	0.3653	0.6383	1.1171	1.8599	3.0993
2.25	0.1397	0.2252	0.3704	0.6454	1.1264	1.8701	3.1072
2.35	0.1426	0.2290	0.3755	0.6525	1.1356	1.8801	3.1150
2.45	0.1454	0.2327	0.3806	0.6595	1.1446	1.8900	3.1228
2.55	0.1482	0.2364	0.3855	0.6664	1.1536	1.8998	3.1304
2.65	0.1510	0.2400	0.3904	0.6732	1.1624	1.9094	3.1380
2.75	0.1537	0.2435	0.3952	0.6799	1.1711	1.9189	3.1455

Table 4. Mesopic luminances determined using the interpolation approach (* The luminance levels and corresponding values were obtained using linear interpolation method, other luminance levels and corresponding values are from CIE mesopic luminance table.)

R_{sp}	Photopic luminance (cd/m^2)						
	0.1	**0.1732***	**0.3**	**0.5477***	**1**	**1.7321***	**3**
0.25	0.0705	0.1333	0.2467	0.4772	0.9130	1.6387	2.9265
0.35	0.0750	0.1392	0.2545	0.4873	0.9253	1.6518	2.9367
0.45	0.0793	0.1449	0.2620	0.4971	0.9373	1.6647	2.9468
0.55	0.0834	0.1504	0.2693	0.5068	0.9492	1.6773	2.9568
0.65	0.0873	0.1557	0.2764	0.5162	0.9608	1.6898	2.9666
0.75	0.0911	0.1609	0.2833	0.5254	0.9722	1.7021	2.9763
0.85	0.0947	0.1659	0.2901	0.5345	0.9835	1.7142	2.9859
0.95	0.0983	0.1708	0.2967	0.5433	0.9945	1.7261	2.9953
1.05	0.1017	0.1756	0.3032	0.5521	1.0054	1.7379	3.0046
1.15	0.1051	0.1803	0.3096	0.5606	1.0161	1.7495	3.0139
1.25	0.1083	0.1848	0.3158	0.5691	1.0267	1.7610	3.0230
1.35	0.1115	0.1893	0.3220	0.5773	1.0371	1.7722	3.0319
1.45	0.1147	0.1937	0.3280	0.5855	1.0473	1.7834	3.0408
1.55	0.1178	0.1981	0.3339	0.5935	1.0575	1.7944	3.0496
1.65	0.1208	0.2023	0.3398	0.6015	1.0674	1.8052	3.0582
1.75	0.1238	0.2065	0.3455	0.6093	1.0773	1.8160	3.0668
1.85	0.1267	0.2106	0.3512	0.6170	1.0870	1.8266	3.0753
1.95	0.1295	0.2147	0.3568	0.6246	1.0966	1.8370	3.0836
2.05	0.1324	0.2186	0.3623	0.6320	1.1060	1.8474	3.0919
2.15	0.1352	0.2226	0.3677	0.6394	1.1154	1.8576	3.1001
2.25	0.1379	0.2265	0.3731	0.6468	1.1246	1.8677	3.1082
2.35	0.1406	0.2303	0.3784	0.6540	1.1338	1.8777	3.1162
2.45	0.1433	0.2341	0.3836	0.6611	1.1428	1.8875	3.1241
2.55	0.1459	0.2378	0.3888	0.6682	1.1517	1.8973	3.1319
2.65	0.1485	0.2415	0.3939	0.6751	1.1605	1.9070	3.1396
2.75	0.1511	0.2452	0.3989	0.6820	1.1693	1.9165	3.1473