

Algorithm Error Study for Photometric Measurement System Transformation

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Received: 19th July 2019, Accepted: 10th August 2019, Published: 31st August 2019

Abstract

The article studies the errors of conversion algorithms for photometric systems using the example of the $C\gamma \rightarrow B\beta$ transformation. The considered algorithms lead to different types of interpolation at the final stage: on scattered data and bilinear interpolation. The authors study the way the error behaves with a different grid pitch of photometric angles and with a different exponent k , which determines the photometric body of a round-symmetric source $I(\alpha) = \cos^k(\alpha)$.

Keywords

Photometric Systems, Bilinear Interpolation, The Interpolation on Scattered Data, Relative Error, Photometric Body.

Introduction

American [7] and Russian [2] standards have the formulas for the transition between photometric systems. But as they showed in [4] there is a number of inaccuracies in these documents that do not allow to use the proposed solutions in practice. It also shows how to combine photometric system correctly, and it is indicated that the data structure becomes irregular after transformation, therefore, it is additionally necessary to interpolate the values of the luminous intensity. It is impossible to generate photometric data files without this [6, 8]. Two options are possible here. If we combine the old system (the system with the original data) with the new one, then the interpolation of the luminous intensity values is carried out in the new system. In this case, the interpolation nodes form an irregular grid, so you need to use the appropriate interpolation (for example, using the Delaunay triangulation) [5]. If we combine the new system (the system in which we want to obtain the values of the luminous intensity) with the old one, then the interpolation of the luminous intensity values is carried out in the old system respectively. In this case, the interpolation nodes form a rectangular grid; therefore, the luminous intensity values can be found via bilinear interpolation [3]. This article studies the error distribution for these methods.

Study Methodology

The following test was developed to study the errors of methods. The photometric body was modeled by a body of revolution, the generator of which was set analytically in the following form:

$$I(\alpha) = \cos^k(\alpha) \quad (1)$$

This function approximates well the light distribution of round-symmetric light sources: office lights, spotlights, etc. As the exponent increases, the light distribution becomes narrower. Thus, one can model the cosine distribution of office lamps, so deep and concentrated among searchlights. Figure 1 shows the distribution curve of luminous intensity (DCLI) for $k = 1, 3, 5, 7, 10$.

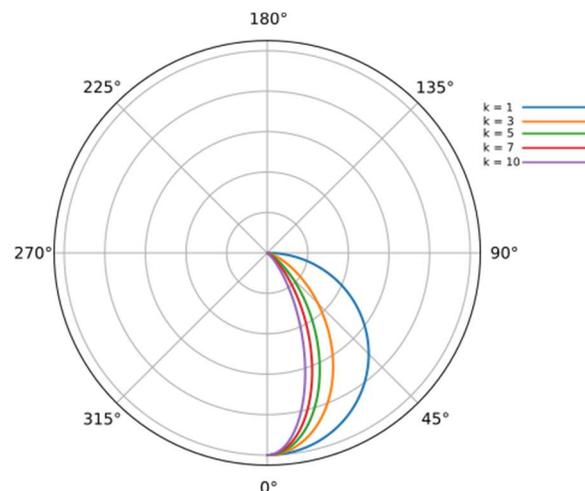


Figure 1: DCLI with Different Indicators of a Round-Symmetric Source Degree

When they describe the steps of the testing algorithm, we will use the notations and presentation style similar to the style in [1]. So, let \mathbf{R} be the set of real numbers. We denote the vector space of all real $m \times n$ arrays by $\mathbf{R}^{m \times n}$:

$$A \in \mathbf{R}^{m \times n} \Leftrightarrow A = \begin{bmatrix} a_{11} & \dots & a_{1m} \\ \vdots & & \vdots \\ a_{n1} & \dots & a_{nm} \end{bmatrix}, a_{ij} \in \mathbf{R}$$

We will refer to the array elements as follows: a_{lj} , where l — line number, and j — column number. We will refer to any column or any array row using a colon. Let's denote the k -th row of the array A ($A \in \mathbf{R}^{m \times n}$) by $A(k, :)$:

$$A(k, :) = [a_{k1}, \dots, a_{kn}] \tag{2}$$

Similarly, let's denote the k -th column of the array A by $A(:, k)$:

$$A(:, k) = \begin{bmatrix} a_{1k} \\ \vdots \\ a_{mk} \end{bmatrix} \tag{3}$$

Now let's consider the testing algorithm directly. Arrays were formed for the specified photometric body, that describe the light distribution in the $C\gamma$ and $B\beta$ systems. Three arrays of the same configuration were created in order to describe the photometric body.

For the $C\gamma$ system:

$$C = \begin{bmatrix} c_{11} & \dots & c_{1m} \\ \vdots & & \vdots \\ c_{n1} & \dots & c_{nm} \end{bmatrix}, C(1, :) = 0^\circ < \dots < C(l, :) < \dots < C(n, :) = 360^\circ, \tag{4}$$

where C is the array of equatorial angles in $C\gamma$.

$$G = \begin{bmatrix} \gamma_{11} & \dots & \gamma_{1m} \\ \vdots & & \vdots \\ \gamma_{n1} & \dots & \gamma_{nm} \end{bmatrix}, \Gamma(:, 1) = 0^\circ < \dots < \Gamma(:, j) < \dots < \Gamma(:, m) = 90^\circ, \tag{5}$$

where G is the array of meridional angles in $C\gamma$.

$$I = \begin{bmatrix} i_{11} & \dots & i_{1m} \\ \vdots & & \vdots \\ i_{n1} & \dots & i_{nm} \end{bmatrix}, i_{lj} = (\cos \gamma_{lj})^k, \tag{6}$$

where I is the array of light power values in $C\gamma$

For $B\beta$ system:

$$B = \begin{bmatrix} b_{11} & \dots & b_{1m} \\ \vdots & & \vdots \\ b_{n1} & \dots & b_{nm} \end{bmatrix}, B(1, :) = -90^\circ < \dots < B(l, :) < \dots < B(n, :) = 90^\circ, \tag{7}$$

where B is the array of equatorial angles in $B\beta$.

$$\beta = \begin{bmatrix} \beta_{11} & \dots & \beta_{1m} \\ \vdots & & \vdots \\ \beta_{n1} & \dots & \beta_{nm} \end{bmatrix}, \beta(:, 1) = -90^\circ < \dots < \beta(:, j) < \dots < \beta(:, j) = 90^\circ, \tag{8}$$

where β is the array of meridional angles in $B\beta$.

$$I' = \begin{bmatrix} i'_{11} & \dots & i'_{1m} \\ \vdots & & \vdots \\ i'_{n1} & \dots & i'_{nm} \end{bmatrix}, i_{lj} = (\cos b_{lj} \cdot \cos \beta_{lj})^k, \tag{9}$$

where I' is the array of light power values in $B\beta$.

For convenience, we agreed to make the pitch of photometric grids the same in both equatorial and meridional planes:

$$b_{l+1,j} - b_{lj} = \beta_{l,j+1} - \beta_{lj} = c_{l+1,j} - c_{lj} = \gamma_{l,j+1} - \gamma_{lj}$$

Since in $C\gamma$ system, in contrast to $B\beta$ one, the optical axis of the luminaire is combined with the polar axis of the goniophotometer, the light intensity for a round-symmetric source will not depend on the equatorial angle C . It is enough to know the light distribution in one of the meridional half-planes, for example, at $C = 0^\circ$, in order to determine its light distribution fully.

Then, the arrays (4–9) were developed for the same analytically given photometric body, and the transformation from $C\gamma$ to $B\beta$ took place using the methods described above. The inputs were the arrays (4-8). And the array of light forces was obtained at the output in $B\beta$ system after conversion:

$$I'' = \begin{bmatrix} i''_{11} & \dots & i''_{1m} \\ \vdots & & \vdots \\ i''_{n1} & \dots & i''_{nm} \end{bmatrix} \tag{10}$$

Then they searched the array with relative errors:

$$E = \begin{bmatrix} e_{11} & \dots & e_{1m} \\ \vdots & & \vdots \\ e_{n1} & \dots & e_{nm} \end{bmatrix}, e_{ij} = \frac{|i'_{ij} - i''_{ij}|}{i'_{ij}} \cdot 100 \tag{11}$$

Results

This section presents the results of the studies concerning the dependence of two method error on the exponent k and on the pitch of the photometric grid (Table 1). It is not possible to give all the graphs of the error distribution in one article, therefore they are given only for the step of 1° (in the equatorial and meridional planes). Also, the error was studied only by the example of the $C\gamma \rightarrow B\beta$ transformation, since the inverse transformation or the transformation into $A\alpha$ system are identical.

| k | Photometric grid spacing | Luminous flux after $C\gamma \rightarrow B\beta$ conversion using bilinear interpolation | Luminous flux after $C\gamma \rightarrow B\beta$ conversion using the interpolation on scattered data | Luminous flux for the reference array (9) |
|---|--------------------------|--|---|---|
| 1 | 1° | 999.95 lm | 1000 lm | 999.97 lm |
| | 2° | 999.81 lm | 999.97 lm | 999.90 lm |
| | 3° | 999.56 lm | 999.76 lm | 999.77 lm |
| | 5° | 998.82 lm | 999.17 lm | 999.36 lm |
| 3 | 1° | 1000.07 lm | 1000.06 lm | 1000 lm |
| | 2° | 1000.29 lm | 1000.22 lm | 1000 lm |
| | 3° | 1000.64 lm | 1000.49 lm | 1000 lm |
| | 5° | 1001.71 lm | 1001.35 lm | 1000 lm |
| 5 | 1° | 1000.12 lm | 1000.09 lm | 1000 lm |
| | 2° | 1000.47 lm | 1000.36 lm | 1000 lm |
| | 3° | 1001.06 lm | 1000.82 lm | 1000 lm |
| | 5° | 1002.88 lm | 1002.27 lm | 1000 lm |

| | | | | |
|----|----|------------|------------|---------|
| 7 | 1° | 1000.17 lm | 1000.14 lm | 1000 lm |
| | 2° | 1000.67 lm | 1000.54 lm | 1000 lm |
| | 3° | 1001.50 lm | 1001.22 lm | 1000 lm |
| | 5° | 1004.04 lm | 1003.33 lm | 1000 lm |
| 10 | 1° | 1000.24 lm | 1000.21 lm | 1000 lm |
| | 2° | 1000.95 lm | 1000.82 lm | 1000 lm |
| | 3° | 1002.13 lm | 1001.83 lm | 1000 lm |
| | 5° | 1005.75 lm | 1004.99 lm | 1000 lm |

Table 1: Luminous Flux Before and After Photometric System Conversion

Conclusion

Figures 2–9 show that, the relative error increases for both methods as one approaches the poles of the Bβ system. And it can reach large values. And at first glance, the method of transformation using the interpolation on scattered data is significantly inferior to the method with bipolar interpolation. However, if you look at the DCLI, it becomes obvious that a large error is observed for small values of luminous intensity (<0.01 I₀), which is not significant from the point of view of lighting practice. Which by the way is confirmed by table 1, which presents the luminous flux before and after the conversion of photometric systems. It also implies that with the increase of k, that is, when a photometric body is compressed, the error of luminous flux determination increases, but even for a concentrated DCLI it does not exceed 0.6%. It is also interesting to note that the errors of the light flux after the transformation of Cγ → Bβ using the interpolation on the scattered data are less than in the method with bilinear interpolation. This suggests that the first method behaves worse only when it approaches the poles of Bβ photometric system. The study showed that you can use both methods in practice.

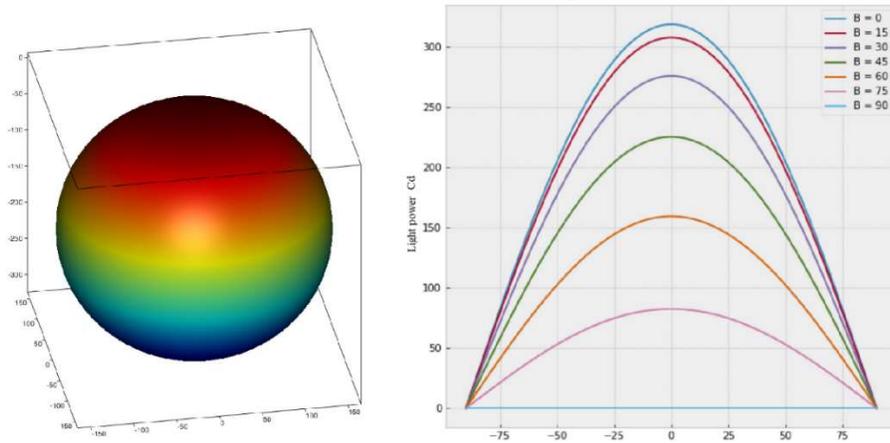


Figure 2: Photometric Body with k = 1 and its DCLI in a Rectangular Coordinate System

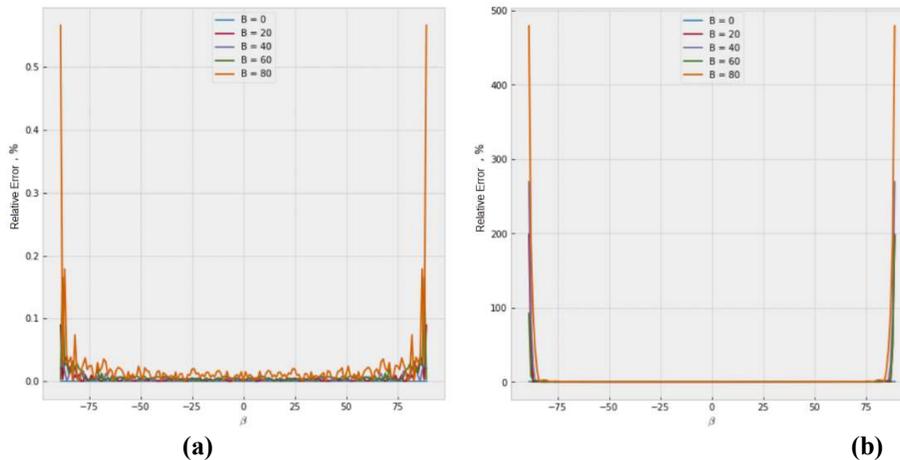


Figure 3: The Error Distribution for the Indicator k = 1: a) After Cγ → Bβ Transformation using Bilinear Interpolation; b) After Cγ → Bβ Transformation using the Interpolation on Scattered Data

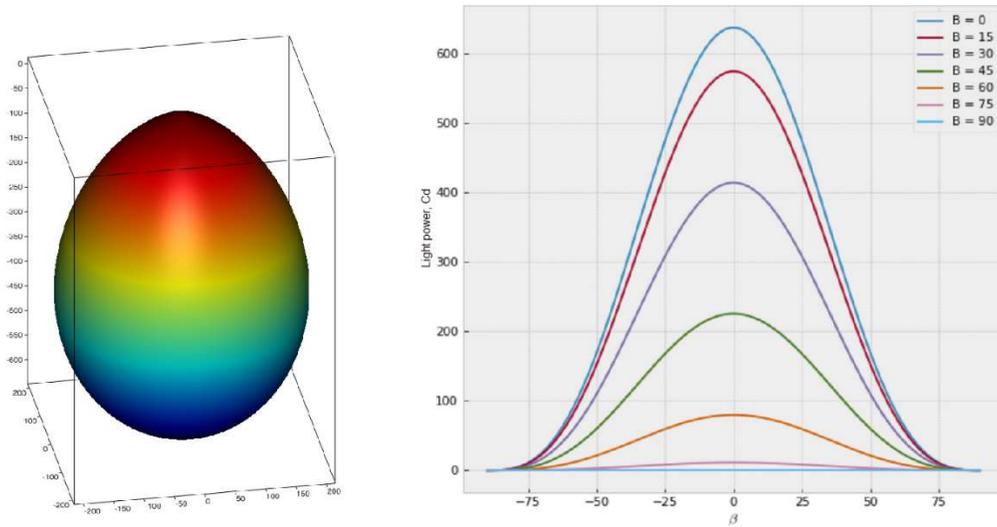


Figure 4: Photometric Body at $k = 3$ and its DCLI in a Rectangular Coordinate System

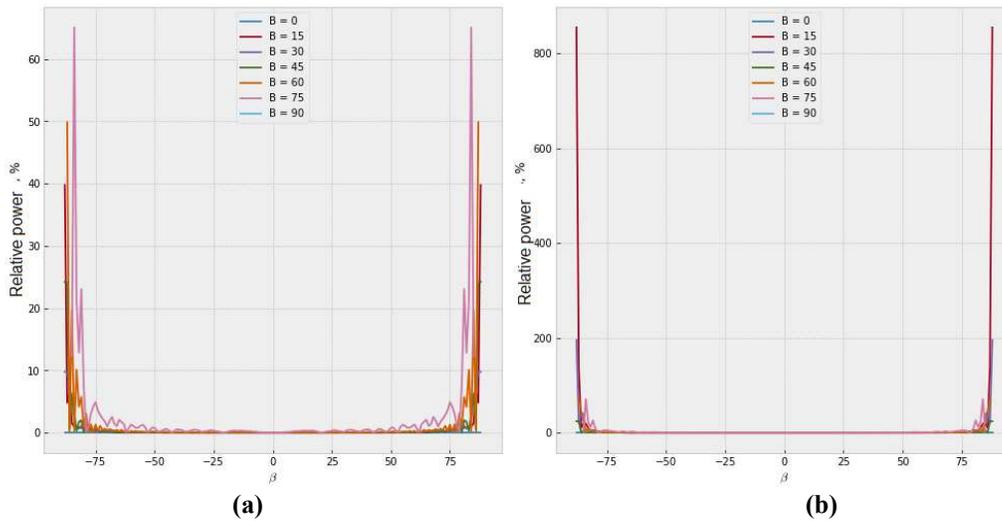


Figure 5: Error Distribution for the Indicator $k = 3$: a) After $C\gamma \rightarrow B\beta$ Transformation Using Bilinear Interpolation; b) After $C\gamma \rightarrow B\beta$ Transformation Using the Interpolation on Scattered Data

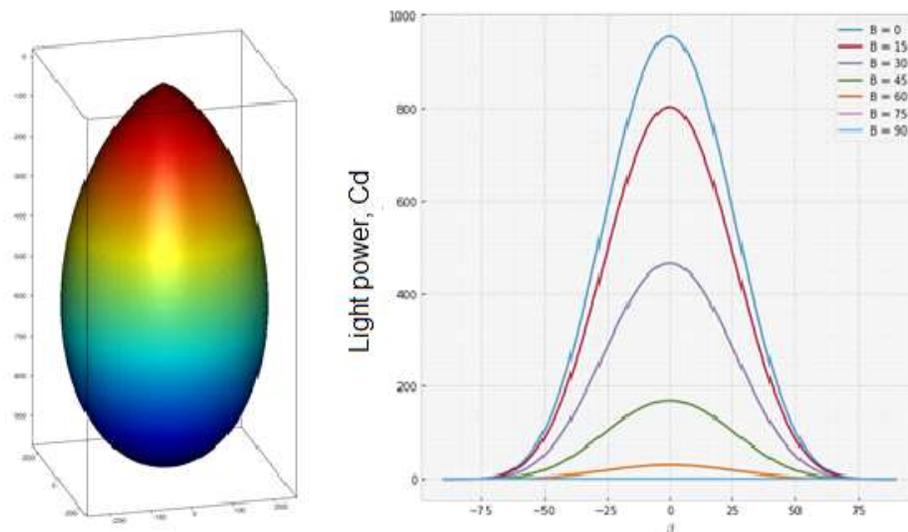


Figure 6: Photometric Body with $k = 5$ and its DCLI in a Rectangular Coordinate System

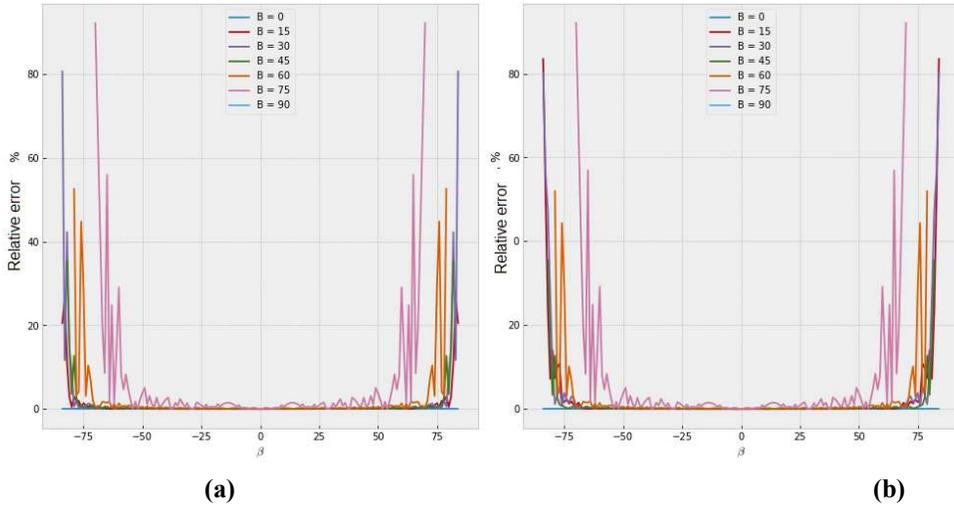


Figure 7: The Error Distribution for the Indicator $k = 5$: a) After $C_\gamma \rightarrow B\beta$ Transformation Using Bilinear Interpolation; b) After $C_\gamma \rightarrow B\beta$ Transformation Using the Interpolation on Scattered Data

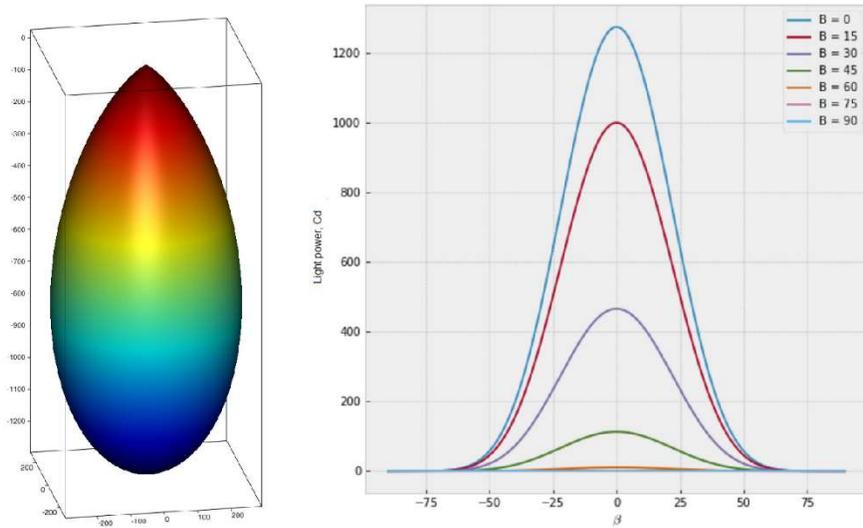


Figure 8: Photometric Body $k = 7$ and its DCLI

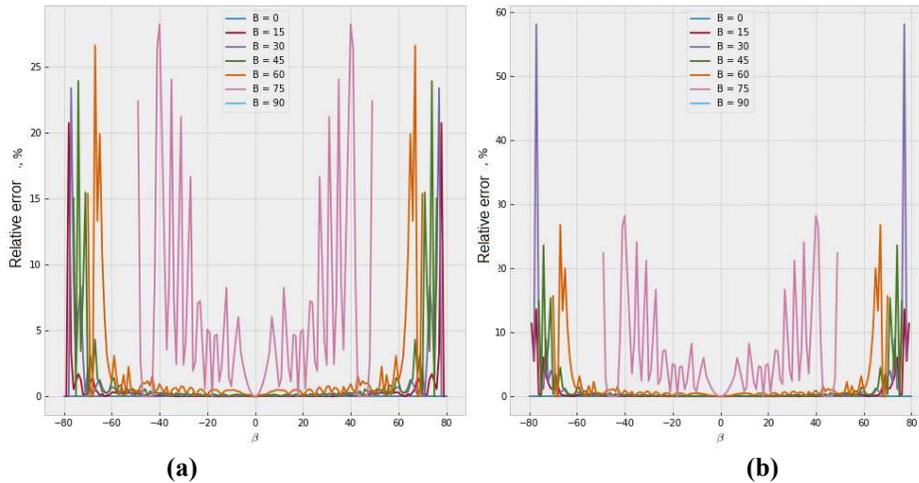


Figure 9: Error Distribution for the Indicator $k = 7$: a) After $C_\gamma \rightarrow B\beta$ Transformation Using Bilinear Interpolation; b) After $C_\gamma \rightarrow B\beta$ Transformation Using the Interpolation on Scattered Data

Conflict of Interest

The authors confirm that the presented data does not contain a conflict of interest.

Acknowledgements

This work was supported by the Russian Foundation for Basic Research. The grant 18-48-130009\18.

References

1. Golub D. Matrix calculations / D. Golub, Ch. Van Long. - M: World, 1999. - 548 p.
2. GOST R 54350 - 2015. Lighting devices. Lighting requirements and test methods. - Intr. 2016 - 01 - 01. - M: Standardinform, 2016. - 42 p.
3. GOST R 55708-2013. Outdoor utilitarian lighting. Normalized parameter calculation methods =: Road lighting. Design methods of normative performances: national standard of the Russian Federation / ed. Federal Agency for Technical Regulation and Metrology. - Moscow: Standardinform, 2015. - 23 p.
4. Prytkov S.V. On the issue of photometric system conversion. / S.V. Prytkov, O.E. Zheleznikova // Light engineering. - 2018. - № 6. - pp. 13-16.
5. Skvortsov A.V. Delaunay triangulation and its application / A.V. Skvortsov - Tomsk: Publishing house of Tomsk University, 2002. - 128 p.
6. IESNA Computer Committee. IESNA standard file format for electronic transfer of photometric data: IESNA lighting measurements series; LM-63 / IESNA Computer Committee. – New York: Illuminating Engineering Society of North America, 1995. – 12 p.
7. IESNA LM-75-01. Goniophotometer Types and Photometric Coordinates. – New York: Illuminating Engineering Society of North America, 2012. – 12 p.
8. Stockmar A.W. EULUMDAT/2 - Extended Version of a Well Established Luminaire Data Format / A.W. Stockmar // CIBSE National Lighting Conference. – 1998. – pp. 353-362.