Study on photometric data visualization based on IESNA LM-63 standard

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Abstract. The luminous intensity distribution (LID) data file is a written description of the spatial distribution characteristics of the light intensity emitted by light sources or luminaires, which is the prerequisite for the accurate lighting analysis, e.g. point-by-point method. Firstly, this paper introduces the format and composition of LID file based on the widely used IESNA LM-63 standard at present. Then, three visualization methods are established to understand the luminaire in an intuitive way. The first one is the photometric curve, which is encoded and integrated into the self-developed lighting analysis software; the second one is the contour map obtained by the rectangular coordinate system in Surfer software through the data exchange file; the last one is the contour map in Origin software represented in the polar coordinate system. It is expected to provide a reference for lighting designers to develop their point-by-point calculation program.

1. Introduction
The fundamental functions of a luminaire are to provide electrical connection with the light source, protect the light source, provide appropriate mechanical characteristics and meet the protection requirements, electrical safety requirements, thermal requirements, marking requirements and photometric function requirements of the shell. Usually, lighting designers are concerned about whether the luminaire can illuminate certain specific areas as they expected and avoid irradiating the light to unexpected places. For example, in the road tunnel, designers always desire that the light can be more concentrated on the road area rather than on the side walls and other areas. This requirement is usually embodied in LID file and offered with each luminaire. The LID file is usually measured by illuminance meter, goniometer, colorimeter or photometer and high dynamic range mapping technique (Cornetto and Suway 2020) to demonstrate spatial radiation characteristics of a light source so that LID curve or luminous intensity distribution curve can be further obtained to graphically describe the spatial distribution characteristics of light sources or luminaires. In the light of LID file of the luminaire, lighting designers can observe the quality of the light spot and calculate the efficiency of the luminaire, the light intensity at any angles, the illumination value at any points and the illumination distribution. In addition, luminaires with reasonable luminous intensity distribution characteristics are also beneficial to improving the uniformity of luminous intensity distribution, luminance uniformity, glare control and other lighting quality indicators.
On the other hand, tunnel lighting system provides only 24 h of artificial sources with a higher amount of electric power consumed during the day (Salata, Golasi et al. 2015). A survey in Europe reveals that the annual electricity consumption is 193.2kw.h/m, and although the lighting system accounts for only 14% of the total installed power in tunnels, its energy consumption exceeds 50% (Dzhusupova, Cobben et al. 2012, Peeling, Wayman et al. 2016). Therefore, there are still many areas that need to be improved in the lighting industry including the researches on artificial lighting sources with high luminous efficiency and new materials for road paving characterized by a higher reflection coefficient than other ordinary asphalts (Salata, Golasi et al. 2015). For instance, an EU Research Project (JRP) called SURFACE aims to offer EU standard organization new traceable reference data, which is representative of the current road surfaces (Iacomussi, Rossi et al. 2017, Gidlund, Lindgren et al. 2019). However, the accurate lighting analysis, e.g. point-by-point method, is still the fundamental procedure to avoid poor design accuracy and achieve energy-efficient lighting system. Hence, it is essential to comprehend the LID file using visualization. The literature on the subject of LID file visualization is hardly available. Gassmann, Krueger et al. (2017) uses the open-source software Visualization Toolkit (VTK) to visualize the LID; (Mandal and Roy 2016) utilizes MATLAB to extract LID file for subsequent lighting visualization and computation; (Siniscalco and Guarini 2018) exploits 3D Studio Max 2016 to couple the geometric model to its corresponding photometric web. Besides, studies are channeling general-purpose software into visualize LID file, such as DIALux (Salata, Golasi et al. 2015, Kralikova, Badida et al. 2017), AGi32 (Kwong and Li 2015) and ProLITE (Moretti, Cantisani et al. 2016), etc.

Most lighting designers in China still employ the traditional and simplified methods such as utilization coefficient method and luminous intensity distribution curve method. The bottleneck is considered to be difficult to understand and operate LID files of luminaires. Obviously, this situation is not consistent with the current trend of the widespread application of lighting CAD technology. The solution is to take the advantage of efficient analysis on the repetitive calculation by computer and promote the utilization of precise analysis methods such as point-by-point method to improve the accuracy of lighting design, thus promoting low-carbon energy saving in the transportation industry. This paper will present the LID file structure and visualization technology based on IESNA LM-63 standard, which is also regarded as the only inputting format for Computer-aided Design and Optimization Analysis Software for Road Tunnel Lighting System (TLCAD&OA) developed by the author, and to then provide a reference for peers who intend to adopt point-by-point method to analyse and design the lighting system in a more precise way.

2. Point-by-point method

The calculation flow of the point-by-point method is shown in Figure 1. Firstly, a calculation area is defined by road width and the longitudinal spacing between any two luminaires of the basic lighting circuit, and a calculation grid with $m$ rows and $n$ columns is established, the intersection of which is the calculation point. Then, the luminares within the influence area, which usually consists of the calculation area and two neighboring zones on both sides, are channeled into calculating the illuminance value of the calculation area point by point and luminaire by luminaire as illustrated by Equation 1. Lastly, the illuminance value of each calculation point is summarized and then the average illuminance, luminance, luminance uniformity and other lighting quality indicators are calculated. In order to increase the calculation accuracy and satisfy the requirements of average illuminance, luminance, total luminance uniformity and longitudinal uniformity, there must be enough calculation points distributed in the calculation area. Usually, it requires ≥5 horizontal calculation points, and the longitudinal calculation point spacing ≤1.0 m, and one row of points should be placed on the center line of the lane.
Define calculation area

Grid & calculation points

Illuminance value $E_{pi}$

Luminance value $L_{pi}$

Luminaires $i$ ($i=1$ to $n$)

Luminaire database & LID files

Average Luminace $L_{av}$

Overall uniformity $U_{0}$

Longitudinal uniformity $U_{l}$

Figure 1. Scheme of point-by-point method for luminance calculation

In the Equation 1, $E_{pi}$ is the horizontal illuminance value (lx) of a certain calculation point $P$ contributed by a certain luminaire in the affected area; $\gamma$ is the vertical angle, namely, the light incident angle of the luminaire corresponding to point $P$ (°); $I_{c\gamma}$ is the light intensity value ($cd$) extracted from the LID file, namely the luminous intensity table (I table) according to the horizontal angle $c$ (°) and the vertical angle $\gamma$; $M$ is the maintenance factor of the light fixture, usually being 0.6 to 0.7; $\Phi$ is the rated luminous flux of the luminaire ($lm$); $H$ is the height of the luminaire light source center to the road surface ($m$).

It can be observed from Equation 1 that LID file of the luminaire, that is, the light intensity table $I_{c\gamma}$, is an indispensable condition for the calculation of the point-by-point method. It should be noted that the LID values are measured at various spatial angles under the default condition that the tilt angle is 0° and the reference luminous flux is 1000 $lm$. However, some manufacturers directly supply the luminous intensity value corresponding to the actual luminous flux of the luminaire, so they should be used appropriately in the calculation. Meanwhile, the attenuation of the light source and the maintenance factor of the luminaire should be taken into consideration. When the luminaire is assembled with rotation angle in any plane, the actual angle corresponding to the test $c$ and $\gamma$ angle should be obtained through the conversion of the plane formula, and then the light intensity value corresponding to the actual angle is gained by consulting the table.

3. Photometric data file

The photometric files are generated in different formats (mostly in relation to the nation where they are acquired/crated) such as Eulumdat *.ldt - Europe, IESNA - *.ies - America, CIBSE TM14 *.cib - United Kingdom, LTLI - *.ltl - Denmark. In addition to these standard files, there are also several proprietary formats used by specific lighting design software, such as the format *.uld of Dialux, the format *.oxl of Litestar or the format *.rolfz of Relux, which are often integrated with a 3D model usually provided by the luminaire manufacturer, but unfortunately, not always properly modeled. Obviously, these latter formats can only be read through the special software mentioned above, whose main purpose is the photometric verification rather than the real non-photorealistic rendering, which cannot be opened with the most commonly used software for photorealistic renderings (Siniscalco and Guarini 2018).

At present, the IESNA LM-63 standard LID file is broadly used all over the world, which is supported by most of China's lighting manufacturers and testing institutions. Therefore, this paper aims to explain the LID file format, as well as the methodology of reading, transferring and visualizing based on the IESNA LM-63 standard.

3.1. Photometric data of IESNA LM-63 standard

The fifth revision of IESNA LM-63 has been published recently. Although this ASCII–based Standard will eventually be substituted with a new XML-based file format, ANSI/IES TM-33-18, Standard Format for the Electronic Transfer of Luminaire Optical Data, both standards are still valid until this transition is completed and this Standard has been abandoned. Therefore, in this paper and in TLCAD&OA, the ASCII–based IESNA LM-63 standard LID file is adopted. The file structure includes the following contents:
(1) The first line in the data file is the version identification, such as the identification row of the 2002 version:
IESNA: LM-63-2002
(2) The second line to the "[TILT]=" line is the part of the keywords, among them, the first four are the required keywords and the other four are alternative but recommended. Each keyword is added with the bracket "]":
1) [TEST] Test report number
2) [TESTLAB] Photometric testing laboratory
3) [ISSUEDATE] Date that the manufacturer issued the IESNA: LM-63-2002 file
4) [MANUFAC] Manufacturer of luminaire
5) [LUMCAT] Luminaire catalog number
6) [LUMINAIRE] Luminaire description
7) [LAMPCAT] Lamp catalog number
8) [LAMP] Lamp description (i.e., type, wattage, size, etc.)
(3) Types of changes in the light intensity output of lamps due to incline:
[TILT]=NONE| INCLUDE| filename
If the output of the lamp does not vary as a function of the tilt angle, TILT=NONE shall appear on this line. However, if the output of the lamp does vary as a function of the tilt angle, TILT=INCLUDE or TILT=<filename> shall be presented on this line. TILT=INCLUDE indicates that the tilt information is contained as part of the photometric file. In this case, four parameters, lamp-to-luminaire geometry, pairs of angles and multiplying factors, angles and multiplying factors, should be channeled into defining the function of the tilt angle. Additionally, TILT=<filename> reveals that the tilt information is in a separate file. The filename shall end with the file extension tlt or TLT (the file extension is not specific).
(4) Luminaire photometric parameters, a total of 14 parameters, are shown as below:
1) Number of Lamps
2) Lumens Per Lamp
3) Candela Multiplier
4) Number of Vertical Angles
5) Number of Horizontal Angles
6) Photometric Type
7) Units Type
8) Luminaire Width
9) Luminaire Length
10) Luminaire Height
11) Nonrectangular Luminous Openings
12) Ballast Factor
13) Ballast-Lamp Photometric Factor
14) Input Watts
(5) Photometric data:
LID data are composed of 1 row of vertical angle series, 1 row of horizontal angle series and several rows of light intensity value series. The number of rows of the light intensity value series is the same as the variable, Number of Horizontal Angles.
[Vertical Angle Series]
[Horizontal Angle Series]
[Series of light intensity values corresponding to the first horizontal angle]
[Series of light intensity values corresponding to the second horizontal angle]
...
[Series of light intensity values corresponding to the last horizontal angle]
Figure 2 interprets the meaning of vertical angle and horizontal angle in the light intensity value list of luminaires. In terms of Class C luminaires commonly used in tunnels and road lighting, the vertical
angle must start at 0° or 90° and end at 90° or 180° while the horizontal angle always starts at 0°. If LID data of the luminaire demonstrates symmetrical, four-quadrant symmetrical, two-quadrant symmetrical and asymmetrical characteristics, the horizontal angle can end at 4 angles of 0°, 90°, 180° and 360° respectively.

It should be noted that the CIE standard and the Chinese standard, namely Photometric Test of Road Lighting (GB 94682) adopted to detect tunnel luminaires are different from the IESNA standard in the definition of horizontal angle. More specifically, in terms of the CIE standard and the Chinese standard, the direction plane of the horizontal angle 0° is along the driving direction while the 0° direction plane specified by IESNA is perpendicular to the driving direction, that is to say, the horizontal angle of these two standards differs by 90°. Therefore, it is essential to pay attention to this significant difference when reading LID file. For instance, in the lighting analysis of street luminaire, it is generally necessary to adjust the inclination angle of the street luminaire on the light pole and the luminaire arm plane (0°–180° direction in IESNA). Similarly, when the pro-beam or counter-beam lighting is configured into the tunnel lighting systems, it is important to transform the horizontal angle and set a correct tilt angle for the luminaire.

Figure 2. Vertical angle and horizontal angle presented in the photometric data file

4. LID visualization technology
Visualization provides an intuitive medium to understand LID files of luminaires, which is crucial for lighting engineers to identify the performance and maximize the potential light energy of luminaires. The following three methods of visualization are introduced.

4.1. The luminous intensity distribution curve of each horizontal angle
TLCAD&OA provides a luminaire library management function, which can be connected to luminaire databases supplied by different manufacturers to view LID files of any luminaires, as shown in Figure 3. In the program, firstly, two one-dimensional dynamic arrays Icr_vertical (m-1) and Icr_horizontal (n-1) are defined to save as the vertical and horizontal angles respectively. The sizes of these arrays are based on variables of Number of Vertical Angles and Number of Horizontal Angles respectively and are dynamically scaled. Secondly, a two-dimensional dynamic array Icr_value (n-1, m-1) is defined to store photometric data. Then, For...Next loop statement and Line Input #nFile statement are utilized to read and store a series of light intensity values row by row. Each row is read into the array Icr_value corresponding to each horizontal angle and each row of data consists of m values separated by spaces. After separated by certain programming skills, the data is stored into the Icr_value array one by one. Taking the luminaire type of 14714 with a power of 48 watts as an example, the vertical angle is from 0° to 180°.
0° to 180°, with an interval of 5°, a total of 37 vertical angles, and the horizontal angle is from 0° to 360°, with an interval of 5°, a total of 73 horizontal angles, so there are 2701 light intensity data.

In the VB.net development platform, the PictureBox control is applied to visualize LID data in the polar coordinate system. The origin is the light center of the luminaire. The vector indicates the magnitude of the luminous intensity in a certain direction. The angle between the vector and the optical axis is the vertical angle. The upper right graph area in Figure 3 is the LID curve of the selected luminaire type of 14714 at a horizontal angle of 90°. It can be observed that its light intensity is concentrated between 0° and 45°.

4.2. Contour map in surfer
Produced by a USA company, Golden Software, Surfer is a software to draw three-dimensional maps (Contour lines, Image Map, 3d Surface). It is used to process X, Y, and Z data, which easily fabricate various maps. Therefore, it is an alternative method to take advantage of this software to demonstrate LID curve of luminaires.

Surfer uses ASCII files as well as their own binary grid format. The fastest way to obtain 2D data from LID file to Surfer is to write those data in the ASCII format. Surfer’s file format is:

*DSAA*

| Ncolumns | Mrows |
|----------|-------|

*Export to Surfer & Origin exchange file*
\text{Xmin Xmax} \\
\text{Ymin Ymax} \\
\text{Zmin Zmax} \\
Z11 Z12 Z13 ... Z1N \\
Z21 Z22 Z23 ... Z2N \\
Z31 Z32 Z33 ... Z3N \\
... \\
ZM1 ZM2 ZM3 ... ZMN

That is, the first line stores the ASCII (text) string "DSAA". The second line is (integers) the number of rows and number of columns. The third is the minimum and maximum \text{X} values. The fourth is the minimum and maximum \text{Y} values. The fifth is the minimum and maximum \text{Z} values.

Starting from the sixth row are the \text{Z} values in the grid. In Surfer’s reckoning, the first row is the one associated with \text{Ymin}. The first row is the bottom edge of the map while the last row is the top edge of the map. The leftmost value in each row is relevant to \text{Xmin} while the rightmost goes with \text{Xmax}.

On the strength of the data standards, LID data of the luminaires can be output into the data exchange format of Surfer, and the contour map in the rectangular coordinate system is adopted to depict the light intensity in Surfer software. Similarly, in regards of Type 14714 luminaire, a luminous intensity contour map as illustrated in Figure 4 can be drawn, in which the abscissa is the vertical angle, the ordinate is the horizontal angle and the filled gray value is the corresponding light intensity value.

4.3. Contour map in origin

The visualization method of luminous intensity distribution data presented in Section 4.1 is integrated into TLCAD&OA. On the one hand, the operation is simple, but its disadvantage is that LID data curve corresponding to one horizontal angle can only be viewed at a time. On the other hand, the contour map created by Surfer can reflect the light intensity values corresponding to all horizontal angles and vertical angles in one graph, but its shortcoming is that photometric data cannot be demonstrated in the polar coordinate system. Therefore, the software also provides a data exchange interface for the output to Origin software.

As an all-purpose and professional mathematical graph analysis software, Origin can assist scientific researchers and engineers to carry out the various data analysis and professional journal quality drawing. Origin’s data format is even simpler, which just output the \(m \times n\) lines of light intensity data to a plain text file in the format of “\text{horizontal angle, vertical angle, and intensity value}”, and then utilize Polar contour theta (X) \(\gamma(Y)\) method in Origin software to create a contour map in the polar coordinate system, as shown in Figure 5 below. Among them, the radial dimension represents the vertical angle, the hoop angle represents the horizontal angle, and the light intensity value is displayed by color.

\textbf{Figure 4.} Contour map of LID file in Surfer  \hspace{1cm} \textbf{Figure 5.} Contour map of LID file in Origin
5. Conclusion
LID file is the basis for the precise lighting analysis of the point-by-point method which demonstrates the incomparable advantages against other simplified calculation methods including the coefficient method. Hence, understanding the structure of LID file and the method of reading in LID data are indispensable for the designers to develop the point-by-point calculation program.
This paper introduces three visualization methods, which are the self-developed luminous intensity distribution curve method integrated into TLCAD&OA software, the method of exporting the data file and representing it as the contour map in the rectangular coordinate system in Surfer, and the contour map in the polar coordinate system in Origin. Visualization offers a friendly user-computer interaction medium, which allows designers to more intuitively understand LID characteristics of any light fixture, to better take advantage of the light effects of the light fixture.

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