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Road lighting and headlights: Luminance measurements and automobile lighting simulations

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Abstract

This paper focuses on lighting dimensioning and lighting quality of traffic lighting. The work considers the factors that are important in creating optimal lighting conditions and luminous environment for night-time driving. The work is based on simulating, measuring and analyzing traffic lighting. The work introduces a new method for road luminance measurements and analysis. For simulation of automobile lights, a new method based on a real scene is introduced.
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1. Introduction

The primary function of traffic lighting is to keep the safety of people. Traffic lighting should provide good visibility conditions and reduce potential hazards by illuminating objects in and along the roadway. The function of fixed road and street lighting is to illuminate the road surface and objects on the road and its surrounding areas. Car headlights in their turn illuminate the road surface, roadsides and, in addition, any non-horizontal objects in these areas. Road and street lighting and automobile lighting are discussed in this paper.

With the enormous increases in traffic volumes, the number of roads is rapidly increasing in China. In year 2000, the main roads in China increased by about 110,000 km including 6500 km of new highways. In the next 20 years, an extensive amount of main roads will be built to connect the main cities in China. In Shanghai alone, the length of the traffic system will be increased by 3600 km in the next 3 years corresponding to a 70% increase in the length of the city roads. It is estimated that

the cars in China will number to 100 million in 10 years. The increasing traffic infrastructure and volumes in China set growing demands for safe and comfortable driving conditions. Because of the big population and the increasing traffic volumes, particularly special attention should be paid to the safety of driving. Fixed road and street lighting and automobile lighting should provide optimal visibility conditions for the road users in varied traffic situations.

The quantity and the quality of road lighting can be analyzed and controlled with road surface luminance measurements. The European standard for road lighting calculations (EN 13201-3) describes methods for luminance calculations and measurements [1]. The dimensioning of road lighting and calculation of road lighting quality characteristics are based on luminance values at discrete points of the road surface. Road lighting measurements are conventionally done with spot luminance meters, which measure luminances of a small (usually 1°) area at a time. The use of spot luminance meters lead to long measurement periods and consequently require the external conditions to remain stabile for several hours. The utilization of an imaging luminance photometer instead of a spot meter eases the luminance measurements and

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gives many new possibilities in analyzing the luminance distributions.

2. Measurements of traffic lighting with a CCD photometer

Luminance measurements of traffic lighting are needed to get data from the field and analyze the luminous environments from the driver's point of view. Road luminance measurements are also a way to secure the quality of road lighting. In this work, road and street lighting luminance measurements were made with an imaging luminance photometer ProMetric 1400. In comparison to a spot meter, it offers new ways to measure and analyze lighting conditions in night-time traffic [2,3], where both the fixed road lighting and automobile lighting are contributing to the luminance scene.

Road lighting calculations and measurements in Europe follow the European standard EN 13201-3 [1]. Because road lighting calculations are made for optimizing lighting conditions for drivers, the observation point is placed 1.5 m above the road surface (Fig. 1). Measuring points are taken 60 m ahead of the observer so that the viewing angle lies between 0.5° and 1.5°. The longitudinal measuring area is

taken from the first luminaire 60 m ahead to the following one on the same side of the road. The transverse measuring area is defined by borders of a driving lane.

According to the European standard EN 13201-3, the luminance points should be evenly spaced in the measuring field and located as indicated in Fig. 2 [1]. The number of points to be concerned depends on the measurement area. The spacing of luminance points in the longitudinal direction is determined from the equation

$$D = \frac{S}{N}, \tag{1}$$

where D is the spacing between points in the longitudinal direction, S is the spacing between luminaires and N is the number of calculation points in the longitudinal direction with the following values: for $S \leqslant 30$ m, $N = 10$; for $S > 30$ m, the smallest integer giving $D \leqslant 3$ m.

In the transverse direction, the spacing is determined from the equation

$$d = \frac{W_L}{3}, \tag{2}$$

where d is the spacing between points in the transverse direction and W_L is the width of the driving lane [1]. The
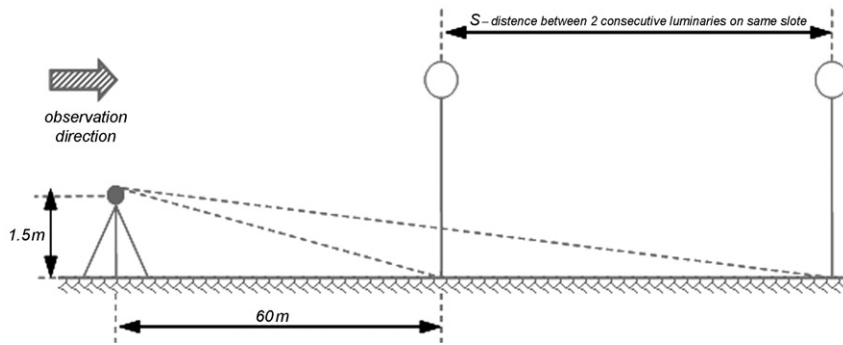

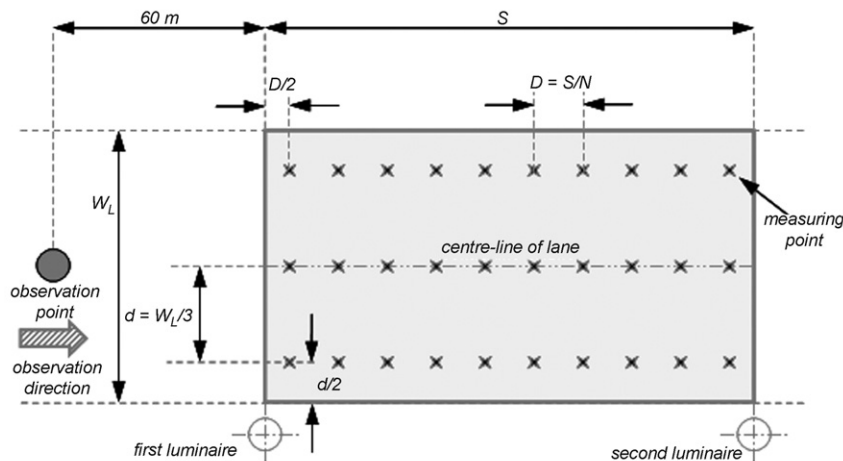Fig. 1. Observation point of road lighting calculations and measurements [1].

Fig. 2. Placement of measurement points of road luminance measurements [1].

spacing of points from the edges of the relevant area is $D/2$ in the longitudinal direction and $d/2$ in the transverse direction (Fig. 2).

In the transverse direction, the observation point is positioned in the center of each lane in turn [1]. The average luminances as well as the overall and longitudinal luminance uniformities are calculated from the measured values. Average luminance and overall uniformity are calculated for the entire carriageway for each position of the observation point, whereas longitudinal uniformity of luminance is calculated for each lane separately. The

operative values of quality characteristics are the lowest ones in each case.

The luminance photometer of HUT Lighting Laboratory is a computer-controlled CCD-based imaging photometer (Fig. 3). The ProMetric 1400 consists of a 2-stage Peltier cooled 14-bit CCD camera, a photopic filter, various lenses and a software for camera control, data acquisition, data analysis and test report generation. The measurement range of the photometer is from 0.005 to $10^{10}\,\mathrm{cd/m^2}$.

The measurement of road lighting luminance data with an imaging luminance photometer is fast. The CCD camera captures the scene within a few seconds and allows image processing. The image consists of 500×500 pixels and, in the measuring process, the luminances of individual pixels are captured simultaneously. The captured luminance scene includes simultaneous luminance data from the road surface, areas surrounding the road and any obstacles in the visual field of the driver [3]. The image is transformed into numerical data, which can be correlated to photometric values. In this way, a luminance map from the image can be built and luminances over the captured scene can be analyzed. The measurement results can also be saved as numerical values for later analysis.

With spot meters, the luminances are taken from several discrete points (Fig. 2) on the road surface and the average luminances as well as the overall and longitudinal luminance uniformities are calculated from the measured values. Measuring road luminance with conventional spot meters is however troublesome and time consuming to

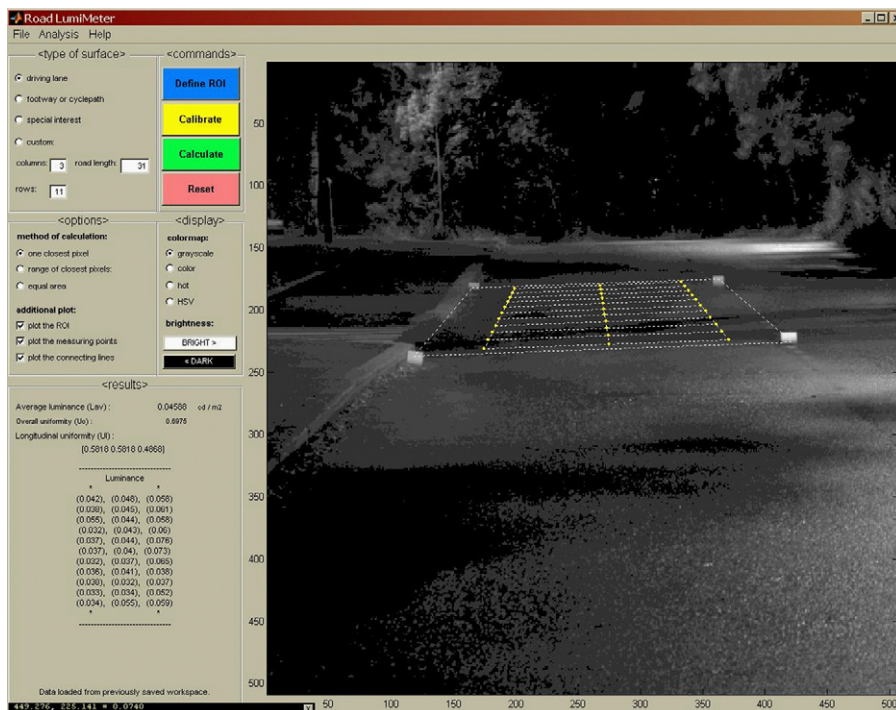Fig. 3. The imaging luminance photometer ProMetric 1400.

Fig. 4. Main window of the computer program Road LumiMeter.

conduct, because there are usually hundreds of luminance points to be measured. The accuracy of the measurements is also highly dependent on the weather and other external conditions as the measurement period can take several hours. In using a spot luminance meter, some details can also escape from the analysis or positional errors can easily appear. With an imaging luminance photometer, the luminance scene is captured within a few seconds and the measurements thus become faster and more accurate. A computer program Road LumiMeter has been developed at HUT Lighting Laboratory to be used along the imaging luminance photometer. The photometer's numerical data can be imported into the Road LumiMeter and calculations of the defined quality characteristics can be made. The program calculates the road luminance parameters defined in the EN13201-3 [1] from the photometer's measurement results. Fig. 4 represents the main window of the program.

A road luminance measurement system based on imaging photometer allows new possibilities for analyzing the visual conditions of driving also in terms of visual targets in the field of view. The evaluation of target visibility levels over the roadway requires the measurement of the luminances of the target, its immediate surroundings and its background. The collection of luminance data point by point from a complex image with conventional spot meter requires carefulness and time. This can be solved by using a CCD camera with an image processor and calculation software, which allow fast evaluations and reports. At the same time, the measuring points can be documented at any time by their representation in the image. The recorded luminance images can also be evaluated later on by taking various quality characteristics into account.

3. Luminance conditions in driving

Luminance measurements in night-time in Helsinki area were conducted with the ProMetric1400 imaging photometer. Fig. 5 shows a luminance distribution of a highway, which was lit with 250 W metal halide lamps. The road surface was dry. The luminance measurements were made according to the European standard EN 13201-3 and the luminance characteristics (average luminance, overall and longitudinal uniformity) were calculated using the Road LumiMeter program. Fig. 5 shows the luminance values as isoluminance areas as well as the calculated luminance parameters for the left- and right-hand lanes. The average luminance of the carriageway is $1.3\,\mathrm{cd/m^2}$. In the surroundings of the road, the luminances vary from mesopic (0.001 ... $3\,\mathrm{cd/m^2}$) to photopic values.

Besides fixed road and street lighting, car headlights have a major impact on the visual conditions, which road users have to deal with. Fig. 6 shows the luminance distribution in a night-time driving situation, where the headlights of an oncoming car are present in the driver's visual field. In this situation, the luminances in the visual field of the driver are more than 100 times higher compared to road surface luminances without the oncoming car headlights. Consequently, the adaptation luminance of the driver is temporarily changed.

Night-time driving is a very complex situation for the adaptation of the eye [4]. The luminances in the visual field change constantly while the car is moving and the direction of view is changing. The luminances of the visual objects surrounding the road (traffic signs, guiding systems, buildings, etc.) may vary a lot depending on the surrounding lighting. Especially in urban areas, the luminances in the visual field are subject to vary and the luminance distribution of the visual scene is non-uniform [3].
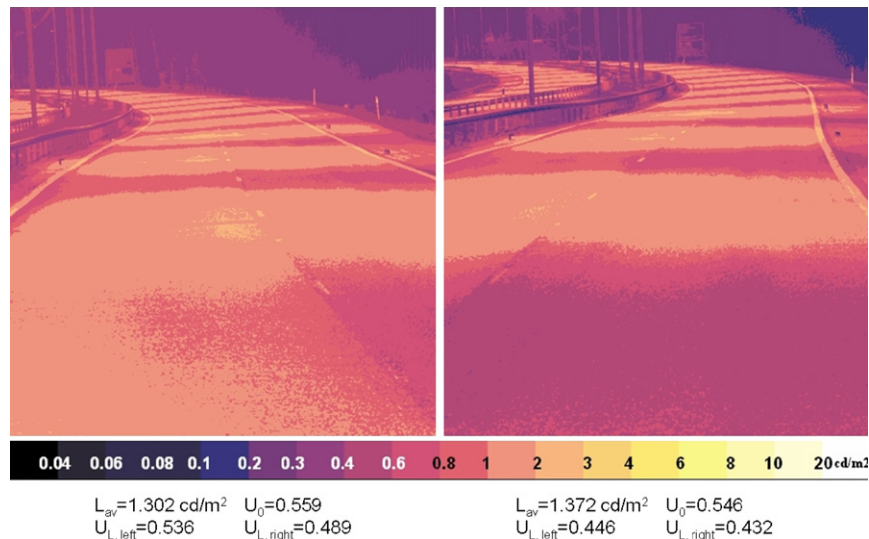

| 0.04 | 0.06 | 0.08 | 0.1 | 0.2 | 0.3 | 0.4 | 0.6 | 0.8 | 1 | 2 | 3 | 4 | 6 | 8 | 10 | 20 cd/m2 |

$L_{av}=1.302\ \mathrm{cd/m^2}$ $U_0=0.559$
$U_{L,left}=0.536$ $U_{L,right}=0.489$

$L_{av}=1.372\ \mathrm{cd/m^2}$ $U_0=0.546$
$U_{L,left}=0.446$ $U_{L,right}=0.432$

Fig. 5. Luminance distribution of a highway measured with the ProMetric imaging luminance photometer. Average luminance L_{av}, overall luminance uniformity U_o and longitudinal luminance uniformities for the left, $U_{L,left}$, and right, $U_{L,right}$, lanes measured from the center of the right lane (a) and the left lane (b). The road lighting is provided by 250 W metal halide lamps.
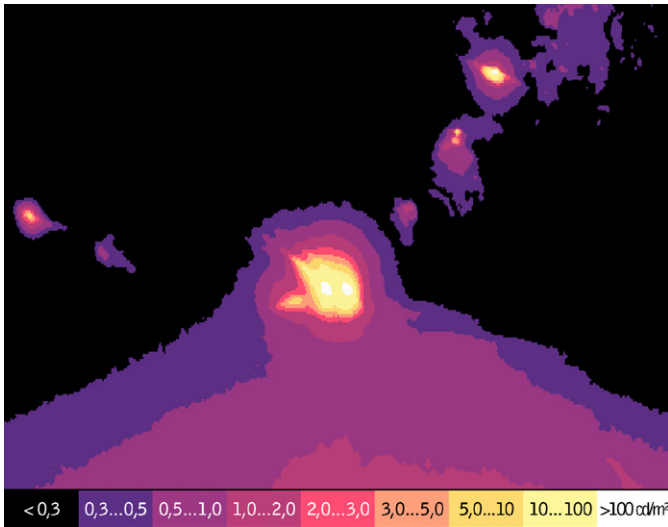
Fig. 6. Impact of oncoming car's headlights on the road luminance distribution measured with imaging luminance photometer.

The road luminance measurements indicate that road surface luminances in road and street lighting are largely in the mesopic region, i.e. below $3 \, \text{cd/m}^2$ even on well-illuminated roads [3]. The luminances can be very low in the adjacent and surrounding areas of the road. There are also higher luminances in the visual field of the driver. These comprise, for example, traffic signs when illuminated, road luminaires and the headlights of oncoming cars.

4. Simulation in automobile lighting development

With the development of modern automotive industry, high-performance automobile lamps have been designed and used. The CAD technique plays an important role in the design of the automobile headlight reflector and lens. With the help of the CAD software, the designer can setup the model of the light source, reflector and the lens and input the data to computer. After calculation, the simulated result of light distribution is given. According to the comparison with that of requested, the design can be modified accordingly and this yields to decreases in the costs of design, shortening of the developing period and increases in the economic efficiency of the design. At Fudan University, a method is developed, which models the light source and simulates the process of reflection [5–7].

In CAD system of automobile headlamps, a very important module is the system which can simulate the beam pattern of headlamps and display the light distribution intuitively. A method to simulate the beam pattern is given in the following.

Generally speaking, there are two methods of automobile light simulation: method based on reflection coefficient and method based on real scene. The advantages of the latter method are that it avoids many complex processes such as absorption, scatter, reflection, etc. A new way to apply this method based on a real scene is presented.

The first step of the whole process is to choose a standard road whose geometrical parameters including the width and length are known. For the sake of precision, there must be no interference from other light sources such as moonlight or streetlights. Then a group of headlamps is selected as standard light sources, whose light distributions on the screen 25 m away have been measured in laboratory conditions. Then a photo is taken of the standard headlamp's lighting effect on the standard road. All the data concerning photos and light distribution of the standard headlamps are given as input values to the computer. Hence, ratios of RGB value of pixels on the photo to illuminance of points on the road can be calculated and corresponding database can be built. In fact, this database contains all complex processes such as absorption, scatter, reflection, etc. According to this database, as long as obtaining the light distribution of a headlamp, the RGB values of all the pixels can be acquired and then a software made to get the simulation. The program structure is shown in Fig. 7.

The expression of the basic principle of the method based on real road scene is given by

$$P_t = \frac{P_s}{E_s} \times E_t, \tag{3}$$

where E_s is illuminance of the point while using standard lamps, P_s the RGB value of the pixel on the photo while using standard lamps and E_t the illuminance of the point while using test lamps. P_t is the RGB value of the pixel on the simulated photo.

Isolux curves on the road and on the 25 m screen that was simulated are given in Figs. 8 and 9. To test the newly developed automobile lighting simulation software, experiments were done to compare real lighting with the simulated picture. First a road was selected. Then illuminances of 18 points on the road were measured and compared with the simulated values. Tables 1 and 2 show the comparison between real and simulated values.

A photo of automobile lighting effect was taken and compared with the simulated picture. The distributions in these two pictures are similar, but the light color in simulated picture deviates slightly from the photo of the
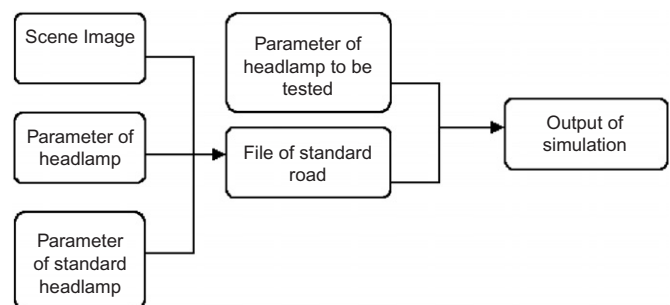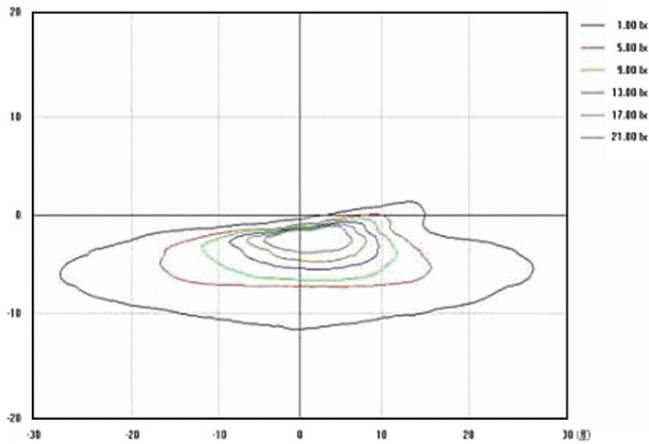

Fig. 7. The program structure.
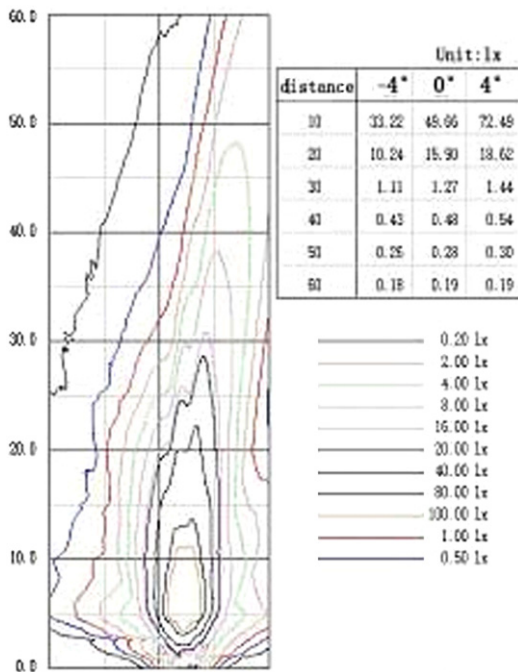
Fig. 8. Isolux curves on the 25 m screen.

Fig. 9. Isolux curves and illuminances of 18 points on the road.

Table 1
Low-beam headlights

Distance (m)	−4°	0°	4°
10	55.89/44.1	72.88/66.9	104.66/85.2
20	5.02/4.7	9.12/6.7	20.16/14.3
30	0.53/0.82	0.74/1.08	1.060/0.88
40	0.29/0.22	0.23/0.31	0.30/0.20
50	0.20/0.11	0.13/0.12	0.18/0.16
60	0.14/0.09	0.08/0.05	0.12/0.10

Comparison of real value (right) and simulated value (left).

real scene. This is caused by the use of the Santana-1 as the standard headlamp to simulate the Santana 2000, as the color temperatures of these two headlamps are different. In

Table 2
High-beam headlights

Distance (m)	−4°	0°	4°
10	3.98/3.26	8.05/8.4	17.77/16.4
20	13.44/17.1	35.13/44.3	90.13/84.1
30	11.0/11.5	31.03/35.5	86.1/63.5
40	7.79/9.4	25.33/27.1	53.96/54.7
50	5.74/7.0	20.67/20.8	31.67/23.2
60	4.24/6.1	16.20/16.1	20.52/20.7

Comparison of real value (right) and simulated value (left).

the future work, this effect will be solved to increase the precision of the simulation.

5. Conclusions

Traffic lighting conditions play an important role in creating an optimal visual environment in driving. To make the design and dimensioning of traffic lighting more efficient and optimal for the road users, several factors should be regarded.

The quality of road lighting installations can be controlled and secured with luminance distribution measurements on the road surface. In comparison to spot luminance meters, road luminance measurements become more accurate and faster with an imaging luminance photometer. Also the analysis of the measured data is easily made more comprehensive. The luminance photometer gives significantly more measurement information than the conventional spot luminance meter. In the luminance scene captured by the imaging photometer, not only the luminances of discrete points are given, but also luminances on the whole road surface area as well as those of the road surroundings and of any objects in the visual field. In evaluating the visual conditions of the driver, it is important that the luminances of the whole visual field are captured.

Simulation offers efficient ways for the development of automobile lighting. For simulation of headlight light patterns, a new method based on a real scene offers several advantages. This method avoids several complex processes such as absorption, scatter, reflection, etc. With the use of the presented simulation methods in the design of headlights, the design process can be made more efficient with decreases in costs and the developing period.

It is important to consider the combined effect of fixed road and street lighting and automobile lighting when analyzing and optimizing the visual environment in nighttime driving. The imaging technology and new type of measurement equipment provide feasible tools for this.

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