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New cost-effective sensor for the characterization of automotive headlamps by measurements in the near field

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Abstract

Nowadays, European Normative regarding headlamp validation evaluates the photometric distribution of the source as a series of illumination values measured at a plane placed 25 m away from the light source. An innovative and inexpensive approach to test this photometric distribution is presented. We propose to sample the luminance field at a plane placed a few centimetres in front of the headlamp displacing a CCD camera at an adjustable number of positions. A specific processing of the sequence images allows simultaneously measuring the direction of propagation through deflectometric techniques and the energy of the light beams leaving the source through photometric techniques. Image-processing techniques may then be applied to these data in order to evaluate the photometric distribution in any predefined distant surface. An overview of the unit, of the measurement principle, and of the main calibrations performed is presented along the paper. In particular, the techniques for the calibration of the global constant converting CCD grey level values into photometric units are described and applied to different distributions. Finally, the comparison of computed illumination maps using the unit with reference measurements at photometric tunnels is presented, showing good agreement and demonstrating the validity of the approach.

Keywords: Automotive; Headlamps; Photometry; Near-field; Optical testing; CCD; Light sources

1. Introduction

Transport by road has been proved to be the most dangerous of all transport modes [1]. In the European Union, European Transport Policy is pursuing objectives as ambitious as to halve the number of accidents by 2010 through improving road safety by using new technologies. In addition, night-time is the most dangerous moment of the day for drivers. It has been shown that, although the traffic at night is only 25% of the traffic at daytime, there is a similar amount of traffic fatalities in both periods [2]. Although a great number of factors are involved in these accidents, such as fatigue or alcohol, the reduction of the visibility of the road is clearly a key aspect of the problem [3]. So, enhancing automotive lighting designs should play a key role in the goal of improving the safety of drivers in night-driving conditions. In this sector, new technologies and source types are being incorporated year after year according to design and fashion trends, while at the same time the headlamp should still provide the best possible illumination of the road in front of the vehicle and avoid glare effect for the rest of the drivers.

Nowadays, headlamp designs are validated in photometric tunnels according to European Normative. In such installations, the illumination distribution is measured in a plane placed 25 m away from the headlamp through a mechanical goniophotometer [4,5], a bulky mechanical device which allows orienting the headlamp with high accuracy towards a distant, point-shaped high accuracy photometer. This approach has the main drawbacks of the mechanical complexity of the measuring system, plus the large space requirements. This has pushed some alternative methods to simplify the measurement to be proposed. One of the most relevant is the multiphotometer, which becomes more compact by introducing a large lens which projects the image distribution in a screen once the headlamp has been placed at its focus. The screen has a number of photometers on it mea-

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suring the final distribution. However, the alignment and the positioning of the headlamp in this system are critical, yielding the whole approach impractical. Recently, the same principle has been proposed using a radiometric CCD camera instead of the multi-detector screen.

In our approach, a combination of deflectometric, photometric and image processing techniques allows to calculate the distribution in any distant surface from a discrete number of measurements performed in a plane close to the headlamp. Hence, the sensor will compute the illumination distribution in the far field from measurements in the near field. In addition, our approach is much more cost-effective than currently used techniques. Although the system has been developed to characterize headlamp distributions, it has been successfully applied to other types of light sources, such as automotive pilots, halogen lamps or even LEDs.

The paper has been divided into five sections. After this introduction we will present the basics of the measurement principle of the unit. Next, the experimental prototype built to demonstrate the validity of the approach is presented. Subsequently, the photometric calibration of the system is explained and the calculated illumination distributions in photometric units will be compared to measurements performed in a reference photometric tunnel. The last section exposes the main conclusions of the work and points out possible applications.

2. Measurement principle

The main sensor in the unit is a commercial CCD camera which is displaced across the measurement plane through a computer-driven two-dimensional motor unit. The CCD camera performs a double sensing task. On one side, it measures the direction of the travelling energy through the position of the pixels where the incoming energy is impinging. On the other side, it measures the energy propagating along each direction through the grey level value of the corresponding pixel. The direction of the travelling energy may be measured from the pixel position by keeping the lens of the CCD camera focused at infinity. This particular lens configuration makes all rays with a given slope to impinge on the same pixel [6], so that they may be identified with a single light ray (Fig. 1). The two-dimensional slope (u, v) of each of the rays may then easily be calculated following:

$$u = \frac{n_x \Delta x}{f'}, \qquad v = \frac{n_y \Delta y}{f'} \tag{1}$$

where f' is the focal length of the lens, n_x (n_y) the number of pixels from the centre of the array along $X(Y)$ axis, Δx (Δy) is the size of the pixel of the CCD along $X(Y)$ axis, and $u(v)$ is the slope of the wavefront along $X(Y)$ axis. The energetic flux value (F) associated to each direction of propagation is then determined using the grey level of the considered pixel. This means for each pixel of a register we collect information on a ray passing through the center of the lens (x, y) with slope (u, v) and energy F.

To completely characterize the illumination distribution in a plane close to the headlamp, the sensor is displaced across the measurement plane in a regularly spaced array of measurement points, registering both the direction of propagation of the energy (u, v) and its amount F at each of the measurement points (x, y). As the total energy recorded in each register depends on the aperture of the lens, a correction factor to compensate for the different areas covered by the aperture (round) and the displacement (square) of the lens is required to properly compute the final illumination distribution.

Once the sensor has acquired a sequence of registers from the luminance field of the headlamp in the near field, the final distribution in the far field is computed. Due to the amount of information collected by the sensor, the classical ray-tracing approach causes very high computational effort. Therefore, a simpler algorithm was preferred based on the projection and accumulation of shifted registers in the final plane. With this approach, the computing time of the far-field distribution is reduced to a couple of seconds. A final calibration step for converting these accumulated grey level values into photometric units is then required, and will be presented in an independent section.

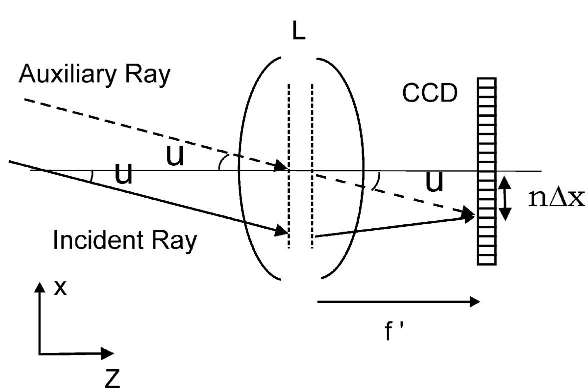

Fig. 1. Measurement of slope (u) with a lens focused to infinity using a CCD sensor.

3. Set up

A robust prototype of the measurement apparatus capable for operation in industrial environments has been constructed, tested and calibrated. The headlamp is placed in a fixed position in front of the sensor. As shown in Fig. 2, a two-dimensional motorized mechanical setup permits the displacement of the sensor along X and Y axes with a positioning repeatability of 10 μm.

The sensor comprises a commercial CCD camera, a lens, a photopic filter, and neutral filters. Furthermore, a frame grabber and a computer are required to record and store the registers in all the positions in the measurement plane. A 1.7:17 lens was selected, with a 17.2 mm focal length and a distortion value below 0.5% in all the CCD area. The illumination fall-off at edge of field due to vignetting was selected to be as small as possible, keeping transmittance over 90% in all the field of view. An equalizing filter and a standard photopic filter achieved a spectral response for each pixel equivalent to that of a standard photometer. Calibrated neutral filters with flat spectral response were used to adjust the sensitivity of the sensor to the energy output of the headlamp. The oscillations in transmittance in the