C8

Spatially Resolved Luminance Measuring Methods Compared with Illuminance Measurements of Automotive Headlamps

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1 Introduction

The lecture gives an overview of applications of image-processing luminance measuring procedures for light distribution measurements of headlamps. Within some fields of photometry measuring technology, these procedures have already become accepted as alternatives to photogoniometers. However, up to now application to headlamp measuring technology has not been possible, because typical high contrast ratios present with headlamp low beam distributions cause large errors due to scattered light. In the context of extensive research, possibilities have been created and basic conditions have been defined which primarily aim at reducing scattered light and so would allow the application in case of light distribution measurement of headlamps.

2 Measuring assignment

The low beam headlamp represents the most complex among the conventional light distributions. The metrological requirements are much more demanding in comparison to those of other headlamp light distributions also. Consequently, the low beam headlamp distribution is considered in greater detail below. Figure 1 shows the low beam headlamp distribution of a Xenon headlamp in pseudo colouring representation (grey scale representation). For the sake of a better visualization of the passive range, a four-decade logarithmic representation has been chosen. The values within the passive area can easily amount to only a hundredth of the values of the active area. Therefore the dark areas can be affected strongly by the bright areas through reflections in the room and/or in the measuring device, if no special measuring procedures are applied. A luminance measurement generally requires only few seconds for determining a complete light distribution because a luminance measuring camera (LMK) instantly reads the complete light distribution with only one image recording. However, the trade-off is that the LMK is subject to more disturbing influence which can lead to several errors. Here the scattered light (see chapter 3.4) exerts the most substantial influence, because the high contrast ratios found particularly with headlamp low beam distributions can lead to large scattered light errors (frequently over 200% of the true measured value).

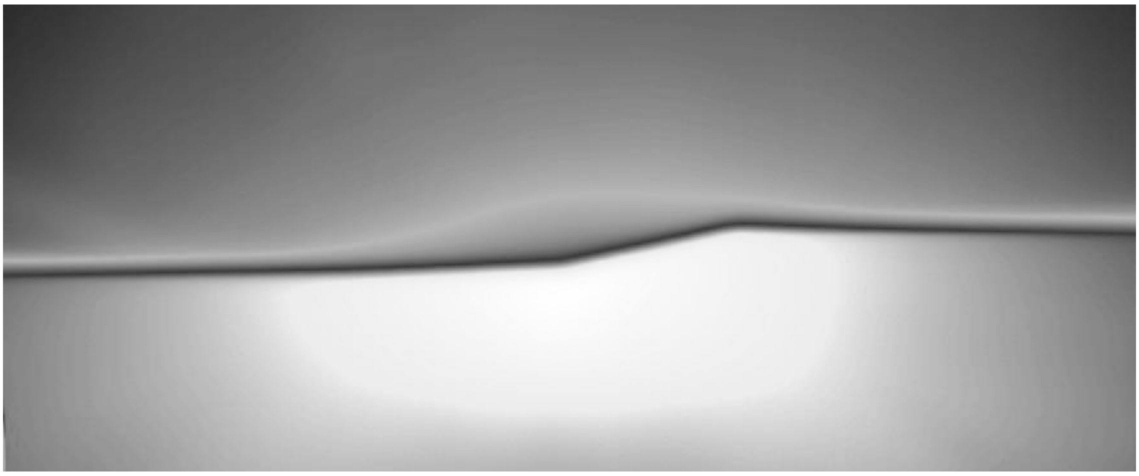

Figure 1: luminance image of a low beam distribution of a Xenon headlamp

3 Measurement setup

The complete measurement setup consists of a measuring device, the laboratory and the projection screen. As measuring device a LMK 98-3 Color from the TechnoTeam Bildverarbeitung GmbH was used. The time advantage over the photogoniometers is significant. The actual speed of the LMK measurement mostly depends on the actual measuring task, the image recording method and integration time [1]. For low beam distributions with high contrast it is recommended to use a HighDyn measurement method. In this case a luminance image recording with suitably adjusted settings takes approx. 35 seconds.

The laboratory was a modified office room of appropriate size (Figure 2).

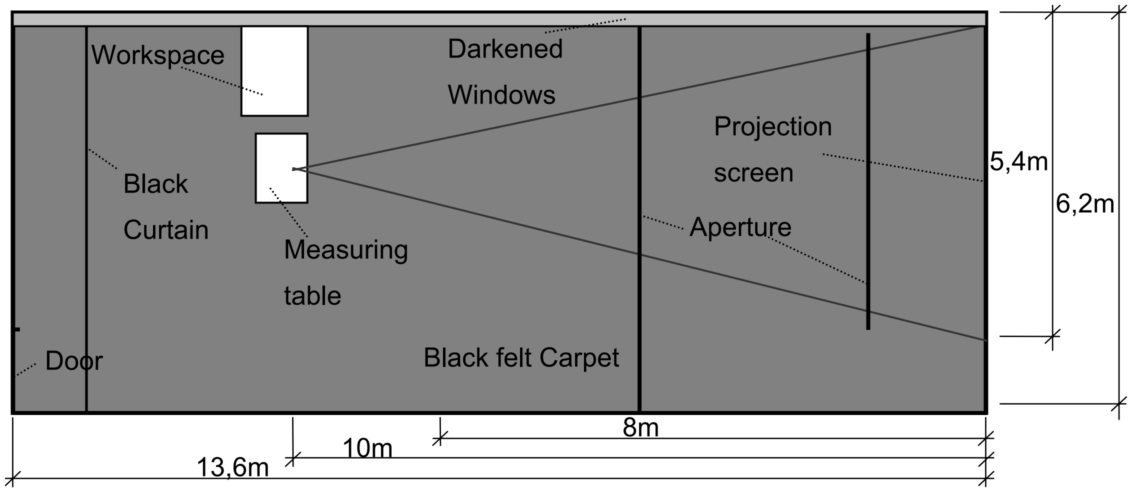

Figure 2: Laboratory floor plan

The headlamp sends light into the complete half space in front of it. So, a theoretical horizontal and vertical angle of beam spread of ±90° is found. However, in general the range with relevant intensities is substantially smaller. Horizontally, the limit is ±50° at maximum, and vertically ±20° at maximum. According to the projection screen size (width approx. 5,4 m, height approx. 2,5 m) and the distance between headlamp and wall, an angle of beam spread of approx. ±15° horizontally and ±7° vertically can be realistically handled. In order to ensure a correct measurement within this range, light which is radiated beyond this angle of beam spread may arrive neither at the reflection wall (multiple reflection) nor – if possible – into the lens of the LMK. Reflections that add to the light on the reflection wall can be eliminated - if at all - only partially. Here the low beam constitutes the highest demands on the measurement setup: Errors resulting from reflection are particularly large if areas of light distribution with high intensities are reflected into areas with low intensities. Here even surfaces with reflection behaviour of less than 10% can have a significant influence. Thus, the primary prerequisite is that the room reflects as little light as possible. In the used room only approx. 0.01 lx of a Xenon headlamp (direct illuminance approx. 400 lx) arrives indirectly at the 10 m projection screen due to reflections in the room. This remaining intensity is of very little influence.

The crucial variable of a projection screen is its reflectance ρ, which depends on 6 parameters: θ and φ of the angle of incidence, θ' and φ' of the angle of

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reflection and the wall coordinates x and y: $\rho = \rho(\theta, \varphi, \theta', \varphi', x, y)$. A good projection screen should have a diffusely reflecting, even (homogeneous) surface, with Lambert characteristic. Moreover, it should reflect light regardless of its actual wavelength. If this condition being fulfilled, the reflectance does not depend on the 6 parameters mentioned any more, but is constant instead: $\rho(\theta, \varphi, \theta', \varphi', x, y)$ = constant. In this case, the Lambertian reflection law is valid:

$$L = \frac{\rho \cdot E}{\pi \cdot \Omega_0}$$

In reality, a Lambertian reflection characteristic is difficult to realize. It can be achieved only a combination of direct and diffuse reflection. If in the case of mixed reflecting surfaces a Lambert characteristic is assumed, the reflectance may vary depending on the wall position (x, y). The same applies for a fixed point to different angles of incident or viewing. The determined (virtual) reflectance can fluctuate due to the portion of directed light or due to the structure, and may result in a value even larger than 1. The projection screen was subject of a visual and a metrological evaluation, with the latter being classified into different experiments. The dependence of θ and θ' as well as φ and φ' of the angle of incidence and the angle of reflection and the local dependence on the coordinates of the wall were examined several times. Due to fixing the measuring set-up, the parameters of influence of the reflectance are reduced to two quantities; the x and y coordinates of the projection screen. In further experiments, it was determined that the projection screen has a constant (virtual) reflectance of 1.07 ±0.05. A big portion of the error (±0.05) can be attributed to the measuring tolerances like errors due to visual positioning, LMK and photometer.

4 Scattered light

In this chapter, the definition, origin and composition of scattered light are explained. Moreover, different strategies for reducing scattered light are discussed. Finally, a new method for reducing it is presented.

4.1 Definition

When measuring light, you have to ensure that only the light which is of interest for the measurement arrives at the measuring device. Light assigned to a pixel which does not originate from the corresponding object point is called scattered or false light. As a result, the picture is lightened evenly (globally) or also unevenly (locally) by scattered light and, thus, falsified. Here, the influence in dark areas of the image is of major significance because only low (less than 1% of the active range) or even no intensities at all are found originally. Therefore, the values measured particularly within dark regions are falsified substantially. Here deviations in headlamp low beam distribution from the actual value of > 200% may occur. As a consequence, the contrast and the dynamic range of the picture are lessened. The reasons for scattered light are undesired reflections and extraneous sources of light as well as dispersion at material transitions.

4.2 Components of scattered light

The scattered light effects assigned mainly to one of the following sources:

1. global (possibly position-dependent) scattered light of the room
2. global scattered light of the camera
3. local scattered light of the camera

The first type has already been explained and quantified above. The room used here is dark ($E \approx 0$ lx) when the measuring object is switched off. Only if the measuring object is switched on, light is reflected onto the wall. In the present case, it is compensated by an appropriate enlargement of the weighting factor of the global scattered light correction (see chapter 4.3).

There is a functional connection between the global scattered light of the camera and the total incidence of light. The local scattered light being defined like a point spread function (PSF), which decreases rapidly and fades out far away (see Figure 4). The two different portions of scattered light in the camera result from the place of their emergence. The global effects result from the dispersion and reflection at optical elements, which are positioned far away from the CCD. These are essentially the individual construction units of the lens. For clarification, Figure 3 shows two possible sources of global scattered light. The figure is neither scale nor realistic but simply illustrates the principle. The middle grey light cone represents the path of rays that map the image of a single point of the object level onto the CCD. This light cone can be scattered e.g. due to the microroughness on the surface of the first lens. From this diffusion a second larger light cone of considerably lower intensity results (represented in light grey in the figure).

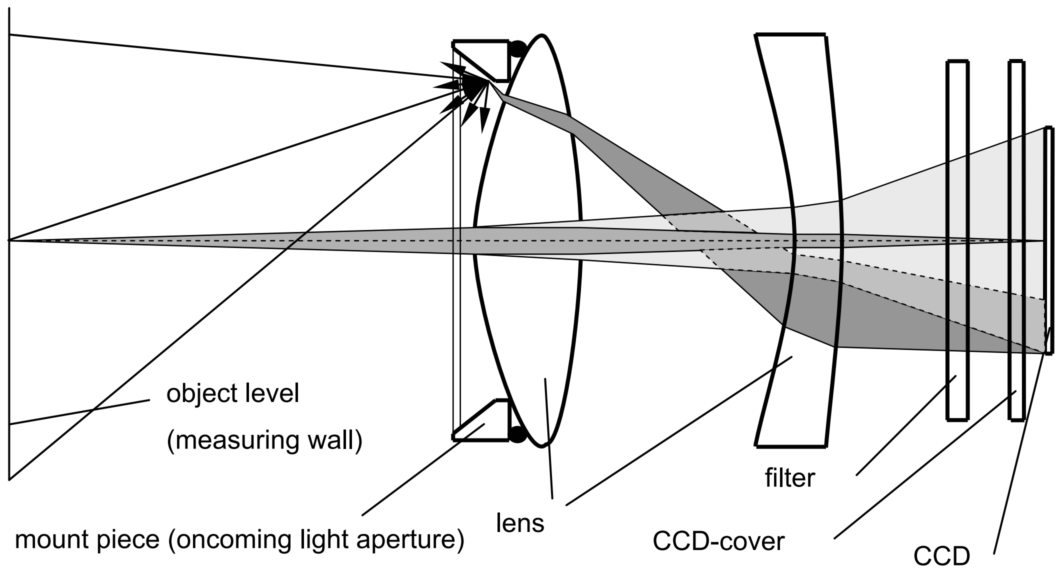

Figure 3: Possible emergence of global scattered light

Because this light cone has a relatively long way to diverge, it can distribute itself over a large part of the CCD or even over the complete CCD. As a second example a reflection at the aperture ring of the lens is represented. Light sent out by any point of the scene (projection screen) falls in (three long black arrows). Afterwards, it is reflected diffusely (short black arrows). If a certain portion of this diffusely reflected light is reflected again into the lens system, the scattered light (represented dark grey in the figure) could be generated. Such effects arise in large multiplicity and superimpose one another. However, the exact strength of the influence exerted by the individual effects is unknown. The materials are treated accordingly so as to counteract such behavior: the aperture ring is painted black and the surfaces of the lenses are polished. Consequently, it is important to treat the lens surface carefully as finger marks or scratches can increase the scattered light substantially.

The filters or the CCD cover glass are positioned closer to the CCD. Reflections occur here, too. However, the distances between the reflective surfaces are considerably shorter. Therefore, the light cones cannot diverge so far, and the effects are locally limited. By multiple reflection and superposition of the light cones of the individual pixels, the scattered light characteristic represented in Figure 4 results.

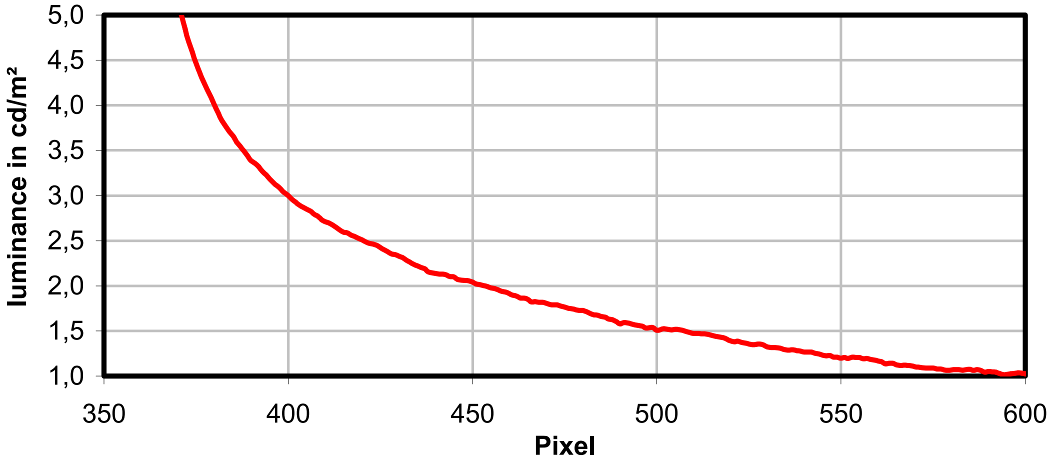

Figure 4: *Scattered light distribution at the cut-off line with an active range of approx. 480 cd/m²*

4.3 Scattered light correction

An image consists of the original picture and an error. Because headlamp low beam distributions are characterized by a high contrast, the scattered light is the substantial error in these images. Another minor influence is exerted by noise. Other errors are of no relevant effect. Thus, an image consists of the original picture, the scattered light and the noise. Scattered light can be considered like a PSF. That means, the scattered light-loaded (disturbed) picture consists of the original picture folded with the PSF and an additive noise: image = PSF * original picture + noise.

Already existing correction procedures for the point spread are based on the following mathematical approach (however, these procedures cannot be applied successfully to the present problem) [3]:

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- determination of the PSF (by functional approximation)
- Fourier transformation of the PSF to obtain the OTF (optical transfer funct.)
- generation of the inverse of the OTF
- Fourier transformation of the image
- multiplication of the inverse with the Fourier-transformed image
- inverse transformation

In practice, the correct determination of the unknown PSF is problematic. If it should really be possible to determine the PSF, the low noise, which could theoretically be neglected, becomes a disturbing factor in the further process. Because the OTF partially shows very small values, even a low noise may exert a big influence. In the present case, the portion of such low values is very high, resulting in very large values when taking the inverse. Thereby, the noise is enormously amplified. The inverse-transformed picture would become non-interpretable [4]. This approach is used in practice mainly for the correction of pictures, which have to bear only a visual evaluation, e.g. in photography or microscopy. Thus, for the metrological evaluation in the present case, this procedure is not suitable. On the one hand, there are values in the frequency range near the constant component which must be determined very accurately. On the other hand, very small values are found, indeed, at higher frequencies which - by filtering with the inverse of the OTF - would be overlaid by the amplified noise. In addition, the PSF results in a narrow, inverse OTF, which is very difficult to realize.

To summarize, it can be said that the known procedures and models do not satisfy the requirements. A headlamp low beam distribution is characterized by a very strong contrast and steep gradients loaded with large local scattered light portions. On these spots, the local scattered light can amount to twenty times the global scattered light, which makes a local scattered light model imperative.

Therefore, a completely new autonomous scattered light correction model was developed. ‘Autonomous’ means that the correction is achieved, if possible, almost independently of the light source, the form of light distribution, the light intensity and also of the position of light distribution in the image. Consequently, the scattered light correction model should be position- and intensity independent and should correct different inputs equally well.

The final algorithm can be divided into a calibrating and an operating phase, which are described in detail in the following chapters.

4.3.1 Approach

Because of the dependence of the scattered light on the original picture, the idea is to determine a scattered light picture by means of suitable operations performed on the original picture. Subtraction of the scattered light picture from the image would then lead to the original picture, which is free of scattered light. Here, particular attention has to be drawn to the fact that the original picture is not known at all. However, for the model approach the original picture can be replaced by the image for the following reason:

Due to reflection or dispersion, a small percentage of light travels from the bright areas of the picture to other areas of it. If these are as bright as well, the effect is only a little one. In dark areas, however, where the intensities correspond only to a small percentage of the bright areas, the effects can be enormous. In turn, the scattered light which originates from the dark areas corresponds only to a small percentage of the intensities of the dark areas and, thus, has almost no effect on these, nor does it exert an influence on those areas presenting higher intensities. Consequently, the scattered light in the picture originates mainly from the bright areas. As for the model approach only the bright areas are important and because a comparison between image and the source picture reveals practically no major differences, the original picture can well be replaced with the image picture in good approximation.

4.3.2 Calibrating phase

The flow diagram for the calibration phase is given below. The main purpose of the calibration phase is to determine the parameters needed for the scattered light correction. These are coupled to the respective measuring system (camera

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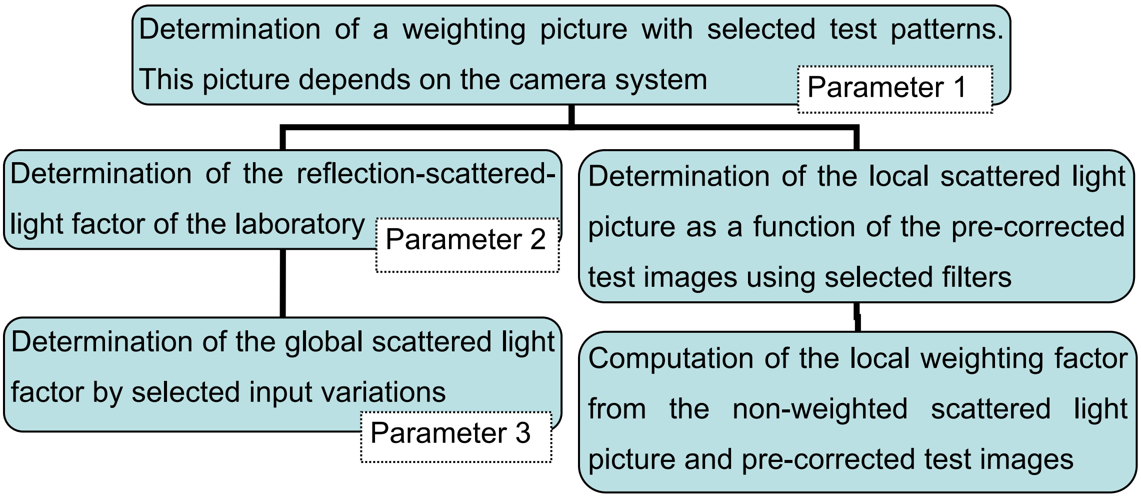
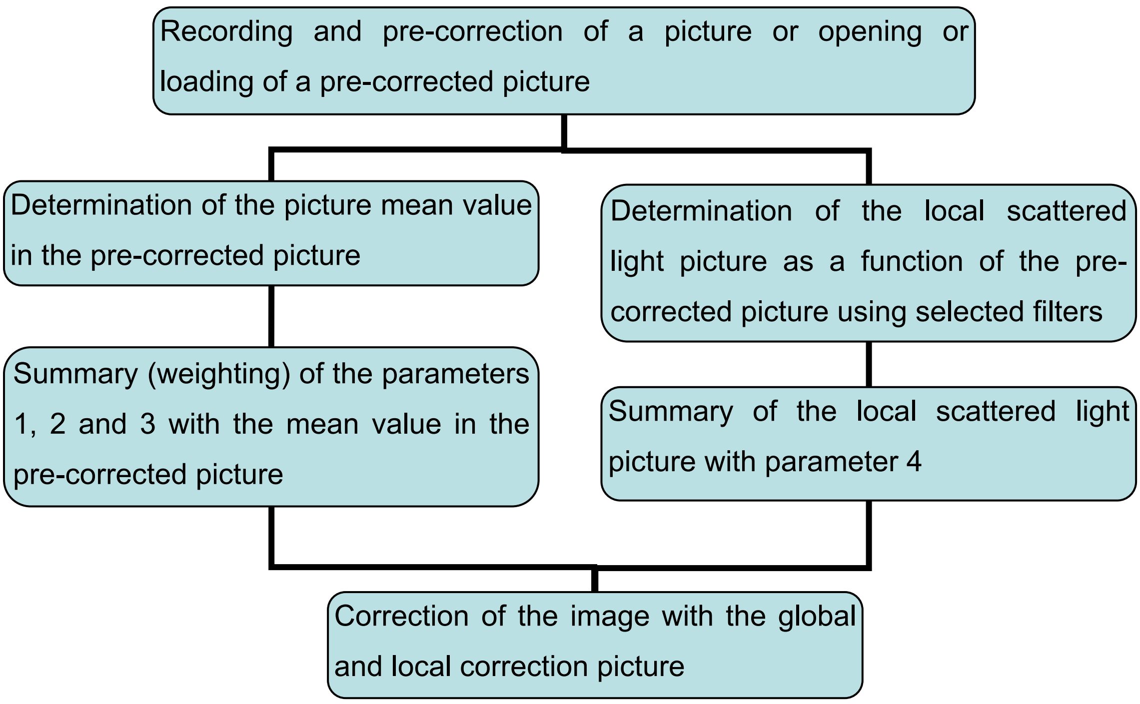
+ lens + laboratory). The calibration has to be carried out just once. However, it is advisable to repeat it at regular intervals just for the purpose of verification.



4.3.3 Operating phase

The operating phase occurs in the running system. Here, the software performs the scattered light correction of the initial picture loaded with scattered light, directly during image recording. This computation is carried out each time an image is recorded. In doing so, not only the parameters determined in the calibration phase are used, but also the current input data (i.e., the image).



5 Results

Figure 5a shows the determined scattered light picture of a Xenon headlamp low beam distribution. Analogous to it, Figure 5b shows the scattered light-loaded headlamp recording, and Figure 5c the scattered light-corrected, both quadruple-logarithmic and as false color representation (represented in gray scales). In Figure 5b the scattered light above the cut-off line extending up to the upper border of the image can clearly be recognized (bright seam). After correction, the scattered light is greatly reduced. For better visualization the vertical intersections through the passive area (see Figures 5a, b and c) are represented in Figure 6.

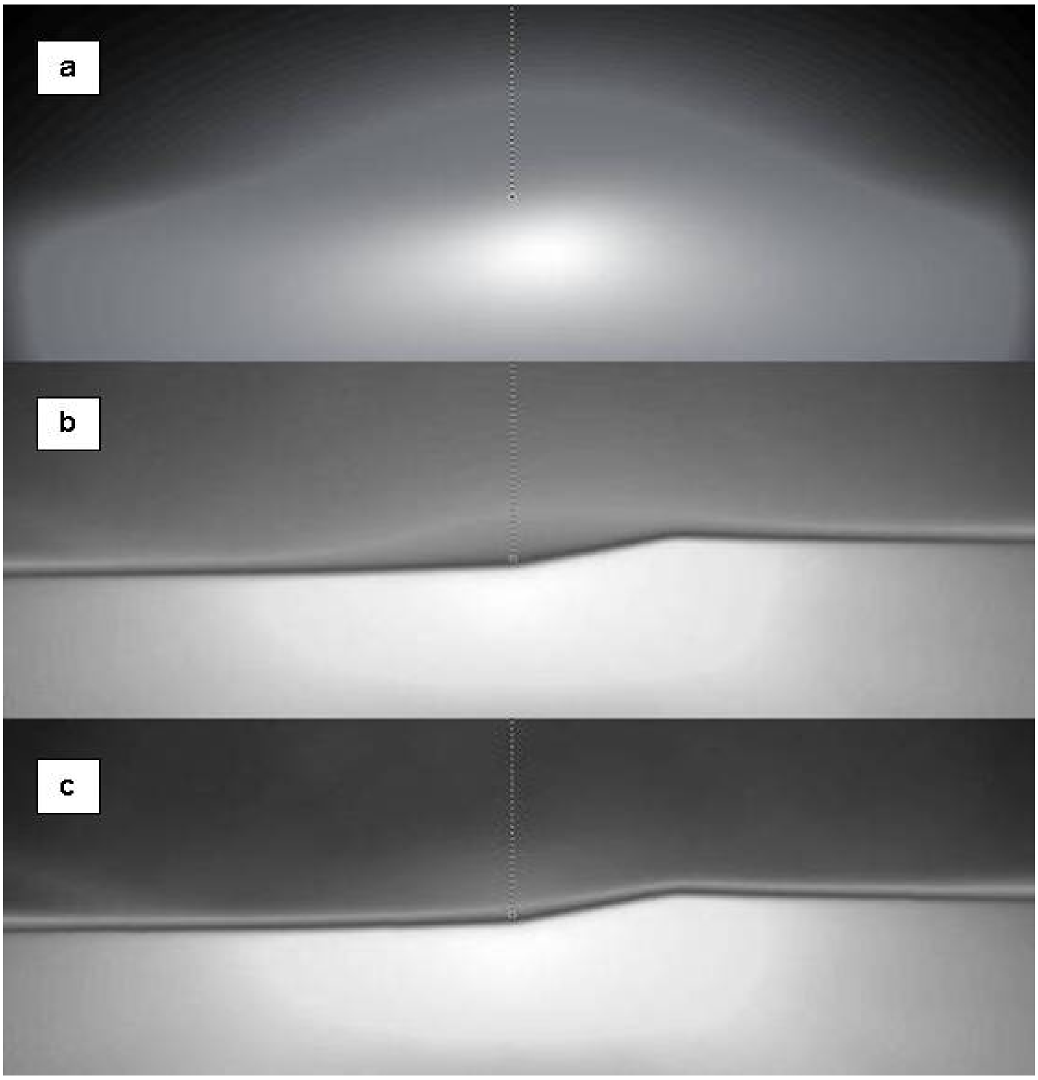


Figure 5 a-c: Scattered light of a Xenon headlamp low beam distribution

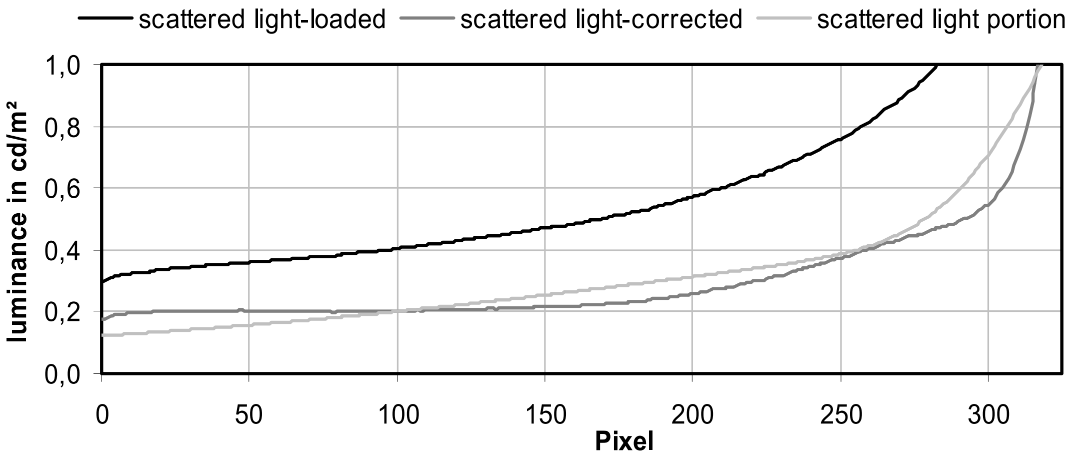


Figure 6: Comparison of the intersections through the scattered light

6 Outlook

A future realization of an automatic identification routine for the elbow point followed by an automatic masking of measuring points is of high interest. With such a procedure the fine adjustment of the light distribution would become redundant. A typical application of such a system would be the quality control in headlamp manufacture.

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