Letter

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Development of HD-headlamps with high-performance projectors

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Abstract: High-resolution headlamp concepts, such as the SSL|HD system from HELLA [1], induce completely new requirements for the evaluation of headlamp light distributions. The subjective perception of image quality is becoming increasingly important compared to the fulfilment of legal lighting values. High-performance projectors allow a good compromise between rapid but theoretical simulations and real but expensive prototypes. These projectors can display different static or dynamic simulations in a realistic way with regard to image quality and light values [2]. This article first introduces the high-performance projectors used for this purpose at HELLA. The projectors can be used to visualize the headlamp light distribution early in the development process, long before prototypes or overall systems are implemented in the vehicle. Following this, two exemplary research questions for static situations are presented, which were answered on the basis of investigations with the high-performance projectors. The requirements for dynamic simulations of real traffic situations, which are described by the interaction of the individual sensors installed in the vehicle (e.g. vehicle dynamics, level sensors, camera), are much more complex. In the paper, a development tool consisting of high-performance projectors and the HELLA simulation software ALiSiA is presented. The aim is a dynamic visualization of the entire system to optimize the development process.

Keywords: automotive lighting; HD-headlamps; homogeneity; illumination; light distribution; road projection.

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1 Motivation

High-resolution headlamp concepts, such as the SSL|HD system from HELLA [1], induce completely new requirements for the evaluation of headlamp light distributions. The subjective perception of image quality is becoming increasingly important compared to the fulfilment of legal lighting values. Finding the best solution in the area of conflict between efficiency, image quality, and installation space and production costs requires a quickly available and reliable basis for evaluation. Prototypes represent the most reliable basis. But in terms of manufacturing costs, they are not a flexible and cost-effective solution. Although simulations are fast and inexpensive compared to prototypes, they provide only a limited validity regarding image quality at the real projection distance, representation of the necessary dynamic range of light values and the subjective effect of dynamic scenes. A good compromise are high-performance projectors that can quickly and realistically display different static or dynamic simulation levels in terms of image quality and light values [2].

2 Realistic projections of simulated headlamp-light distributions

Two high-performance projectors in the light channel of HELLA make it possible to visualize the current product at any time during development. The light channel is an indoor, completely dark and 140 m long light testing facility. It has a real road surface that was manipulated to represent a typical state of use and represents mainly road classification R3 [3]. One projector enables the visualization of a headlamp with the following characteristics:

- Luminous flux: about 3,000 lm.
- Resolution: 1920 × 1200 px.
- Illumination area: 15° horizontal × 10° vertical (most frequently used setting).
- Maximum illuminance: 240 lx (most frequently used setting).

The centre of the exit area of the projectors is 65 cm above the road surface. The forward tilt provided by a headlamp is considered by simulation and not by installation position of the projector. The projectors can be moved horizontally. This allows different vehicle widths to be represented. Besides light distributions, images or video files can be displayed.

The advantage of using the high-performance projectors compared to observe simulations on monitors is the valid representation, especially regarding realistic perception conditions in terms of stereoscopic accommodation in a three-dimensional environment as well as the achievement of realistic lighting conditions due to the roadway and not a screen or monitor as a viewing area. The setting in the light channel imitates a road, which is illuminated with realistic luminous flux by the high-performance projectors. The evaluation of light distributions can be carried out independently of special software knowledge under constant conditions. The comparison of light distributions over different points in time is therefore also possible. For this reason, the created setting is particularly suitable for carrying out evaluation studies. Either experts or novices can be interviewed. In the following sections, two exemplary research questions, which were answered by using the setting with high-performance projectors, will be presented.

3 Exemplary research field 1: homogeneity of headlamps

3.1 General questions regarding homogeneity

Homogeneity is an important evaluation criterion for headlamp light distributions. It is also a “soft” criterion: different people evaluate the same phenomenon in very different ways. There is no generally accepted consensus on which parameters (and which combinations of parameters) an inhomogeneity is assessed as noticeable, disturbing or even unacceptable. Compared to the relevance of this phenomenon, there is very little research [4–6]. This is due to technical reasons: in order to investigate the relationship between the physical stimuli and their perception by the observer, the individual parameters for example luminance ratios, gradients or positions must be systematically varied. To identify possible interaction effects, combinations of these parameters must also be considered. This leads to a very high number of light distributions which must be investigated. Conventionally, each of these distributions must be generated with a pair of prototype headlamps especially designed for this purpose. This is not possible with real headlamps. Here high-performance projectors are very useful, because these projectors can generate any desired headlamp light distribution with realistic luminous intensities. Examples are displayed in Figures 1 and 2.

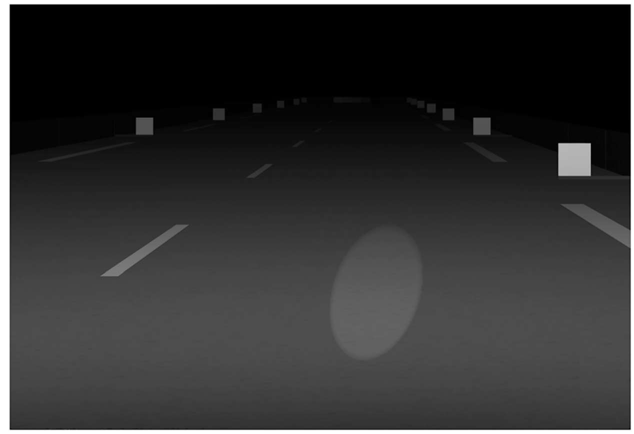

Figure 1: Example for investigated inhomogeneity: round structure with high positive contrast and small gradient [7].

The projectors thus enable the systematic variation of parameters. Further test persons can evaluate the light distributions and their specifically introduced inhomogeneities regarding their perceptibility or their disturbing effect. Using this approach, the investigation of inhomogeneities is possible with reasonable effort. Initial investigations provided consistent results [7, 8].

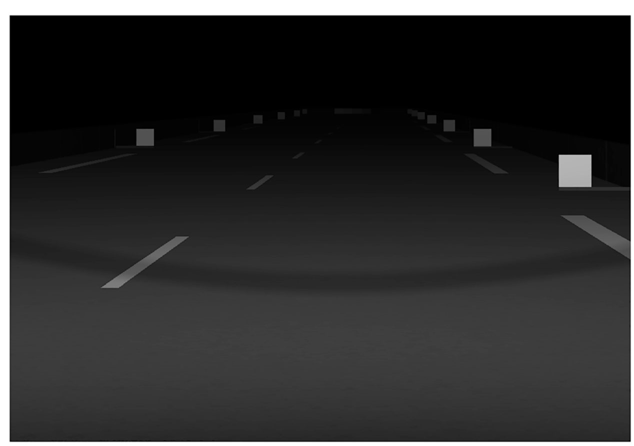

Figure 2: Example for investigated inhomogeneity: annular structure with high negative contrast and small gradient [7].

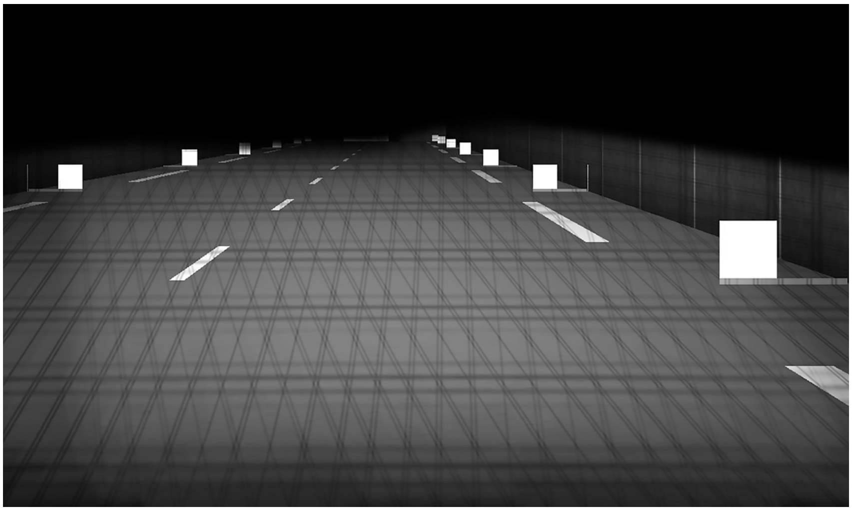

Figure 3: Example for a research question considering homogeneity for HD-headlamp systems: projected grid structure of an image-generating device (strongly exaggerated for visualization).

3.2 Specific questions regarding homogeneity for HD-headlamp-systems

HD-headlamp systems have an imaging element, such as SSL|HD, DLP or LCD, which determines the number of pixels. The high resolution also raises new questions regarding homogeneity.

In order to benefit from the high resolution, the imaging elements should naturally be as "sharp" as possible. However, there are also circumstances which can result in certain "blurriness" as an advantage. Every imaging system has a separation of the individual pixels (in the SSL|HD the separation between the individual LEDs, in the LCD the conductor paths, in the DLP the gaps for the mechanical tilting of the mirrors). An exaggerated visualization of the effect in a light distribution is shown in Figure 3. This raises the question if this separation is visible and if yes: how much blurring is necessary to prevent the perception of such a structure under any circumstances.

Furthermore, the degradation or even failure of individual partial light distributions is at least statistically more probable with thousands or even millions of pixels. The consequence of pixel loss is illustrated in Figure 4. Projectors represent a good approach to investigate if this is visible at all, and if so to develop strategies to minimize the perceptibility of pixel dropouts.

4 Exemplary research field 2: parameters for projections of HD-Systems

4.1 General questions regarding headlamp projections

The development of high-resolution headlamp systems allows the projection of symbols in front of the vehicle. In this way, information like warning or navigation symbols can be transmitted. Until now, the ECE regulations do not

Figure 4: Example for a research question considering homogeneity for HD-headlamp systems: defective elements of an image generating device (strongly exaggerated for visualization).

provide symbol projections. In recent years, a lot of work has been done to evaluate the usefulness and risk of distraction of symbol projections ([9–11]). The studies show a potential benefit from symbol projections. However, it is often stressed, that the exact appearance of symbol projections is decisive for the outcome.

Multiple factors influence the exact appearance of symbol projections: besides the headlamp's properties, the symbol's design and the nature and duration of displaying the symbol play a role. Using prototype headlamps for evaluating the effect of headlamp systems, e.g. with different image quality, is not possible due to efficiency reasons. A reasonable alternative is the use of different simulations in the light channel. Various headlamp properties, for example the optical systems used, can be displayed. The symbols can be projected via the high-performance projectors allowing for realistic luminance levels. With this presentation form a fast switching between different systems is possible. In addition, the observer always retains the same perspective, which is not possible with a direct comparison of multiple prototype headlamps. Thus, different technologies can be compared directly with each other.

There are still many questions that have not been conclusively clarified in the area of high-resolution headlamps: Which parameters are relevant for a good recognizability? Which contrast is optimal for symbol projections? At what distance must symbols be displayed in order to be easily recognized by the driver and without distracting from the driving task? How complex may symbols be at most? To answer such questions, studies can be carried out with high-performance projectors. In the next section, one example research question will be presented.

4.2 Specific questions regarding headlamp projections

In the development of HD-headlamp systems, a compromise between efficiency and image quality must be made. Low efficiency reduces the system's total luminous flux, low image quality leads to blurred appearance of the symbols. A study with test subjects was carried out to analyse whether low image quality can be compensated by animating the symbols. The hypothesis was that the blur is perceived less strongly through the movement of the symbols.

About 41 people took part in the study. Besides the high-performance projectors, two apron modules have been used to illuminate the area directly in front of the vehicle. The subjects rated 18 different symbol projections: three symbols (construction site, turning arrow and HELLA logo) were presented with two simulation models and with three different types of animation. Depending on the considered region of the symbol, the Weber contrast was between 1.2 and 3.6. The construction site and the HELLA logo were presented statically, glowing and approaching. During the animation "glowing", the symbol became lighter and darker and at the same time smaller and bigger, so that a pulsating impression was created. During the animation "approaching", the symbol appeared further back and then approached the test persons. For the turning arrow the animation "building up" was chosen instead of "approaching", what meant that the arrow was built up from the lower end to the tip? The symbols "construction site" and "turning arrow" were displayed on the street in the apron area.

The correct distortion of the symbols was already checked during the preparation of the study using the high-performance projectors. Figures 5 and 6 show examples of the simulation variants for the symbol "construction site".

The symbol "HELLA logo" was projected on a white wall in 10 m distance. After each symbol, the test subjects rated the symbols on a six-point scale regarding contrast, recognizability and irritation. The study showed that the recognizability of the symbols was generally given because the test persons did not disagree with the statement, "The symbol was easy to recognize". For the static symbol, the ratings were between 2.9 and 4.3. The animation of the symbols did not lead to a major change in the perception of contrast or recognizability (effect size smaller than one scale point) but was instead a cause of greater irritation for the test persons (effect size larger than one scale point).

The study is an example of how the projectors in the setting of the light testing facility can be used for the development of light-based assistance systems and the design and evaluation of symbol projections.

5 Evaluation of the complete system

With the help of the high-performance projectors used at HELLA, lighting systems can be simulated and visualized realistically long before the overall system is implemented in the vehicle. The temporal behaviour and the direct influence of all individual components involved in the overall system, such as the lighting control, the optical system and the interfaces, can also be simulated and therefore considered. For this purpose, the proprietary software, ALiSiA, which stands for Advanced Lighting Simulation Architecture, is developed.

Compared to static simulations, the requirements for a dynamic simulation of a real traffic situation, which is

Figure 5: Construction site symbol: simulation variant 1.

Figure 6: Construction site symbol: simulation variant 2.

described by the interaction of the individual sensors installed in the vehicle (e.g. vehicle dynamics, level sensors, camera), are much more complex. The representation of reality is achieved by recording all relevant sensor data that serves as input for the simulation. The recorded data are fed into the simulation synchronously, so the temporal behaviour of the interfaces, e.g. CAN, is taken into account. By replaying the simulation, the influence of individual parameters on the lighting control can be examined and, if necessary, further optimized. A recorded driving situation is repeated, and the relevant parameters are adjusted until the desired behaviour is achieved. In this way, even complex and dynamic processes, such as different swivel strategies for dynamic bend lighting or the behaviour of glare-free high beam, can be evaluated and adapted to customer requirements. Of particular interest is the evaluation of new lighting functions, which can be realized by high-resolution headlamps.

Light distributions can be evaluated in the light channel via a visualization of both headlamps on a 10 m wall or via the projection on the road surface. The development tool ALiSiA allows storing light distributions of headlamp modules with different properties, e.g. resolutions, to examine the influence of these varied properties on a light function. The direct influence of the individual components on the overall light output is particularly traceable when both headlamps are projected into the recorded video image of a real traffic situation. This makes it possible to simulate complete lighting systems on a standard PC. This also allows systematically determining and evaluating the advantages of HD-systems over conventional headlamp systems.

6 Summary

The use of high-performance projectors in the light channel in combination with simulation tools offers a fast and very flexible way of testing headlamp systems. On the one hand, the effects of different parameters of the headlamp system can be considered already during the development process. On the other hand, the observation approach can be used for the development of lighting functions, for example symbol projections. The possibility of carrying out studies with test subjects in this setting provides a neutral and reliable approach to evaluate headlamp systems beyond the assessment by experts. In addition, the approach allows to face the increasingly shorter innovation cycles and to consider different aspects in parallel during the development process.

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