Integrating Headlight Glares into Driving Simulations Based on Human Contrast Perception

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Abstract: The aim of this work is to simulate glaring headlights by measuring the effects of glare on human contrast perception and including the results in a driving simulator.

As contrast perception is highly subjective, two psychophysical experiments were performed. For different glare intensities and durations, the recurring contrast perception of the subject was recorded. Further, varying background illuminations were incorporated. The results have been integrated into a driving simulation by adjusting the display contrast. Afterwards the implementation was evaluated in a field test.

The modified night driving simulation provides a more realistic visualization and enables the analysis of critical traffic scenarios including headlight glare.

This leads to a better transferability of driving simulator results to reality and enables a deeper research of the interaction of oncoming vehicles and advanced driver assistance systems.

Keywords: Human Contrast Perception, Tone Mapping, Glare, Driving Simulation

1. Introduction

During night drives, glare effects can sometimes restrict the view of the driver (see Figure 1). Advanced driver assistance systems, as the adverse weather light for wet, heavily reflecting roads, are utilized to minimize this threat. Other light-based assistance concepts, such as marking critical objects as an attention control, could become a glare source themselves.

The development of those assistance systems is often based on virtual tests in a night driving simulation. Such simulator studies offer the possibility to examine the driving behavior in critical traffic situations under controlled conditions. However, to be able to draw transferable conclusions from simulated test data on the driving behavior, the visual quality of the simulation has to be perceptually realistic.

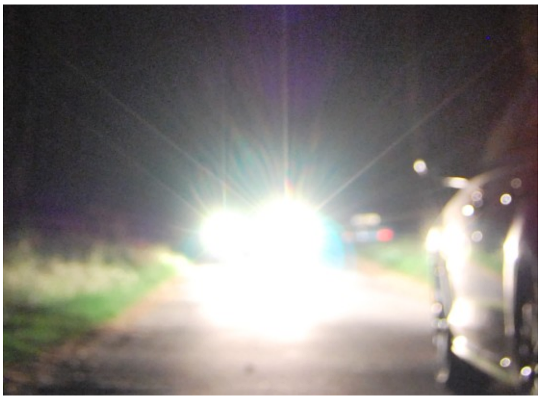

Figure 1: Headlight glare can vastly reduce the view of the driver

Unfortunately, the brightness level of modern headlights cannot be reproduced by commercially available displays. For testing novel advanced driver assistance systems interacting with oncoming vehicles, a realistic glare effect is necessary in order to generate authentic driving behavior. As consequence the impact of headlight glare on the driver has to be emulated.

The occurring limitations on the human vision due to glare effects are highly subjective however. Hence, to be able to adequately incorporate glare effects in a driving simulator, the impact of different glare scenarios has to be measured first.

The rest of the paper is organized as follows: Chapter 2 covers the most important publications in the domains of psycho-physical user studies as well as approaches in computer science. Chapter 3 describes the setting and results of a self-conducted user study measuring the recurring contrast perception after glares of varying duration and intensity. In Chapter 4 this study is extended to different adaptation levels. Chapter 5 validates the measured results through a field test. The test data is then integrated into a driving simulator, as described in Chapter 6. Chapter 7 and 8 give a short conclusion as well as an outlook of planned future work.

2. Related Work

The adjustment of digital images incorporating human contrast perception has been a research topic over the last two decades [1], [2], [3]. Yet, the simulation and visualization of human eye readaptation after being dazzled is a rather novel subject. A few approaches have been presented during the last years, dealing with similar problems. Based on subjective test results of different experiments, both Ledda [4] et al. and Pattanaik et al. [5] visualize the adaptation process for humans under changing illumination levels by adjusting the displayed perceivable contrast. As they only consider the perception of fully adapted subjects, their test results are not applicable for the simulation of short-time glares. Ritschel et al. [6] and Yoshida et al. [7] deal with the visualization of glares and focus on visualizing the perception of the light source itself. In [8] Ritschel describes an approach for simulating after images resulting from glare sources. The simulation of the contrast perception after short-time glares has not yet been addressed in realistic rendering.

Glares have been a research topic in cognitive psychology for many years. According to Olson et al. [9], the effect of glares is twofold. Besides the impact to the human perception (disability glare), a glare can cause discomfort (discomfort glare). Since in this work we are only interested in the changed contrast perception, discomfort glare is neglected.

Ranney et al. [10] analyzed in a stationary driving simulator the long-term effects of glares in the exterior mirrors on truck drivers. Reading et al. [11] explored the re-adaptation times of 83 subjects between 17 and 66 years after glares with white and yellow light. They discovered a positive correlation between the age and the re-adaptation time. Relying on this work, we excluded subjects over 40 years from our measurements.

In another work of Olson et al. [12], the re-adaptation of drivers after glares from both low and high beams were observed. They concluded that for further investigations of the effect of glares, the subjects need to be adapted not to scotopic but to authentic illumination levels.

Johannson et al. [13] inspected in an explorative experiment the impact of after-glare effects under driving conditions by varying the duration and intensity of the glare, as well as the contrast differences between object and background. Even though they considered the relevant parameters, their experiment was performed with completely adapted subjects and cannot readily be transferred to a realistic traffic scenario. Krebs et al. [14], [15] analyzed in several experiments the wavelength dependent impact of glares on the re-adaptation time of the eye for scotopic vision.

The described user study-based observations are hardly transferable to a real driving situation as they all have been carried out under laboratory conditions not reflecting road traffic constraints. Also, previous work was aimed at different goals and thus does not provide sufficient data about subjective contrast perception after short-time headlight glares.

We therefore perform several novel user studies ensuring realistic environmental conditions by reconstructing authentic lighting conditions. The gained test data can then be adapted to simulate the human contrast perception after headlight glare.

3. User Study for varying glare intensities and glare durations

3.1 Experimental Setup

In our first experiment we determined the influence of different glare intensities and durations on the emerging limitations of the human vision. For this purpose, we measured the recurring contrast perception of dazzled subjects with a threshold vs. intensity (TVI) test, as proposed by Hood et al. [16].

An automobile headlight was installed at a distance of 4 meters, generating glare stimuli for different glare distances. To ensure an authentic glare luminance the light exit field of the glare source was adjusted to generate the same perceived exit field as for a real headlight. Further, the light source was dimmed to achieve realistic illuminance values.

The glare direction was chosen to be similar to a glare from an oncoming vehicle. The subjects had to fixate a given point on the projection screen, generating an angle of 6 degree between the viewing and the glare direction. This way, the typical driver avoidance behavior of fixating the right roadside was reconstructed.

Furthermore, the usage of a normal headlight assured that the projected light distribution resembled reality. The laboratory was completely isolated and a constant background illumination of 0.25 lux was established. Thus, the experiments of all subjects had been carried out under the same conditions. The prevailing lighting conditions corresponded to a starlit night with a half moon and fall under the mesopic vision.

After a sufficient pre-adaptation time (3 minutes minimum), the glare stimulus was activated and the subjects were dazzled. Meanwhile, they stare at the given fixation point, ensuring the comparability of the results. After the glare, the recurring contrast perception of the subjects were measured. For this purpose, a grey square was projected on projection plane in front of the subject (see Figure 2). The square was sized at approximately one degree angle of sight (equally sized to the fovea) and roughly corresponded to critical obstacles (as animals) at a distance of 50 meters. The subject then had the task to lower the brightness of the projected square by pressing a button till he could not distinguish the square from the black background any more. As the optical system of the subject recovered from the glare, the contrast perception increased until the adaptation state was reached.

Figure 2: Screenshot of the test program, after a glare. The subject has to adapt the bright square such that he just cannot see it any more. With his eyes readapting to the darkness, the square becomes visible again and has to be redarkened.

Hereby the projected square became recognizable for the subject again, whereupon he re-darkened it. After a preadaptation and instruction phase of ten minutes, including two first test and calibration runs, every subject had to complete eleven test runs with different glare durations and intensities. As glare distance of the simulated approaching car: glare intensities for a 10 meter, 25 meter 50, and 100 meter glare were simulated. The glare lasted 2.5, 5 and 10 seconds. Note that we dropped out one test scenario, as a short glare duration with low intensity yielded no test results, The order of the different glares was chosen randomly for every subject to minimize the influence of possibly occurring learn effects.

Overall, we tested 28 subjects between 21 and 39 years, with an average age of 28 years. To minimize gender specific influences, we enforced (nearly) uniformly distributed sampling with 16 male and 12 female subjects. Subjects with glasses or any eye diseases or surgeries were disregarded. Further, we conduced a minor pre-test with the *Mesotest II* and rejected subjects with a major contrast perception disability.

3.2 Results

The measurement process discussed in chapter 3.1 provides information about the subjective individual contrast perception given the described glares. A generalized perception curve can be obtained by averaging over all test data for one glare. Especially for the lower contrast levels, the variance between the subjects starts rising. However, a clustering of the subjects is hardly possible as the contrast perception is depending on many different factors. Not only permanent attributes of the subjects, such as light sensitivity or short-sightedness, can influence the test results, but also situational factors, as the physical and psychological constitution of the subject or degree of tiredness of his eyes, have to be considered. For one generalized perception curve, it is hence possible to simulate the average minimal perceivable contrast over time, for a specific glare.

Plotting the contrast curves for the eleven tested glares together yields a family of graphs, see Figure 3. Through interpolating between the shown graphs, new perception curves can be obtained and thus every glare with blend parameters between the minimal and maximal test values can be displayed.

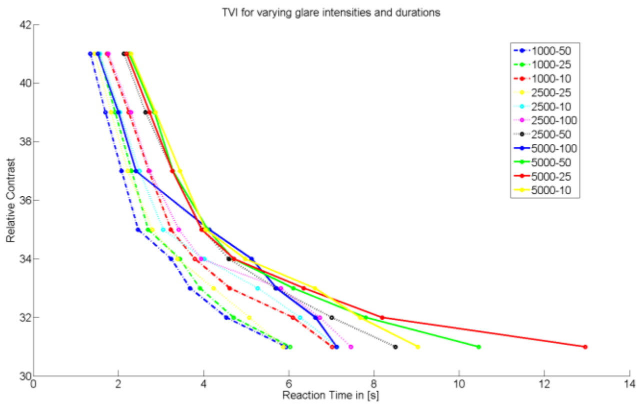

Figure 3: Averaged graphs of the test results. On the x-axis: elapsed time after the glare in seconds, on the y-axis: minimal distinguishable brightness, compared to a black background. The glares were parametrized by its duration (2.5, 5 and 10 seconds) and intensity (by simulating a distance of 10, 25, 50 and 100 meters).

It is noticeable however, that for varying glare durations the contrast perception curves are easily distinguishable (see Figure 4), whereas for static durations and varying glare intensities the perception curves seem to be relatively close to each other (see Figure 5). This leads to the assumption, that the protective reaction of the eye was at its maximum for all tested glare intensities, and thus only the glare duration (and thus the depletion of Rhodopsin) needs to be considered.

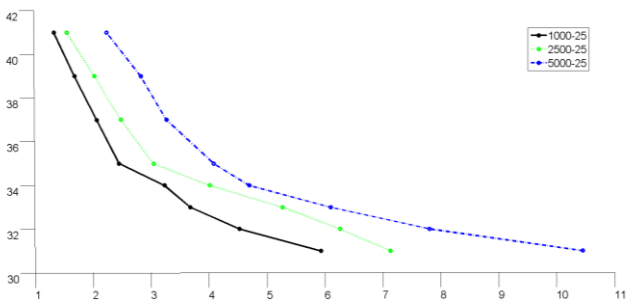

Figure 4: Averaged graphs for varying glare durations, at 25 meter. On the x-axis: elapsed time after the glare in seconds, on the y-axis: minimal distinguishable brightness, compared to a black background.

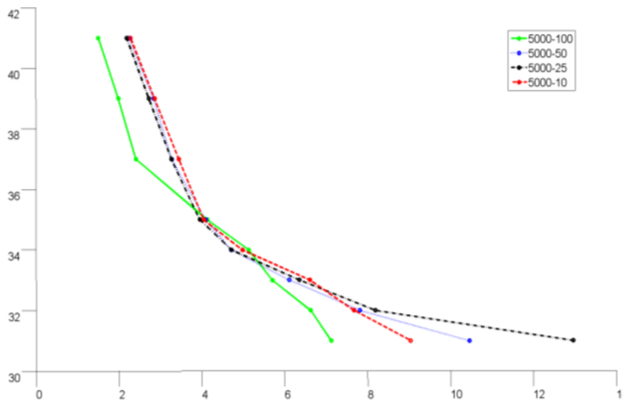

Figure 5: Averaged graphs for varying glare intensities, with a 5 second glare. On the x-axis: elapsed time after the glare in seconds, on the y-axis: minimal distinguishable brightness, compared to a black background.

In order to ease both the interpolation between the measured perception curves and their implementation we generalize the measured values to mathematic describable functions. The best approximate values are gained from the function type $A = (x - B) + C$, with A being a shearing value and B and C displacements in x- and y-axis. Interestingly, a logarithmic approximation yields inferior results. Based on these parameterized mathematical curves, it is now possible to generate new perception curves for untested glare parameters. For glare intensities and durations between the tested values the new function parameters are gained by a linear interpolation between the four (three for long intensive and short weak glares) neighboring tested glares, weighted by their barycentric coordinates.

4. User Study for varying adaptation luminances

4.1 Experimental Setup

The duration of the exposure to a glare source as well as its intensity are clearly two main factors concerning the resulting visual impairment, but they are by far not the only parameters to consider. As described by Baer et al. [17], the prevailing background illumination also highly influences the perception of glare sources. Hence, we further conducted a user study with fixed glare parameters, but varying lighting conditions.

The setting of the experiment was copied from the previous study, ref. Chapter 3. Thus, the subjects were dazzled for a short time by an automobile headlight and their contrast perception was measured afterwards with a TVI test. This time, we kept both the glare intensity and the duration constant – we simulated a glare distance of 25 meters for 1 and 5 seconds. However, the subjects had to pre-adapt to different background luminances, varying from 0.0 lux (absolute darkness) to 0.5 lux (early dawn, or street with streetlights), with 0.1 lux and 0.25 lux as intermediate steps.

The background illumination was generated by two 1x1 meter light boxes, providing a constant and homogenous lighting. Further, the boxes were pointed towards the back wall and the laboratory was completely covered with black cloth, ensuring that the contrast perception test remained unaffected by reflecting streylight.

In this user study, we acquired data sets from 37 subjects between 23 and 40 years, with an average age of 31 years. 21 of these data sets were generated by male and 16 by female subjects. We monitored that no subject took part in both experiments, and again, rejected subjects with a major contrast perception disability based on a pre-test with the *Mesotest II*.

4.2 Results

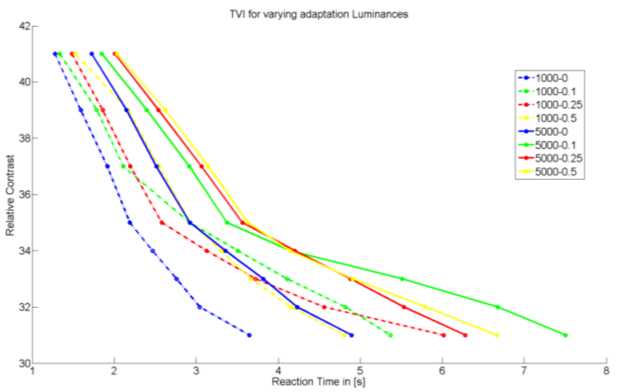

Figure 6: Averaged graphs of the test results. On the x-axis: elapsed time after the glare, on the y-axis: minimal distinguishable brightness, compared to a black background. The glares were parametrized by its duration (1 and 5 seconds) and the background illumination (0, 0.1, 0.25, 0.5 lux).

The averaged results are plotted in Figure 6. As can be seen, the resulting contrast perception graphs feature several intersections, in contrast to the graphs for constant background illumination and changing glare duration.

The main reason for this behavior lies in the influence of the adaptation luminance itself. For low background illumination, the driver is heavily dark adapted. In this case, the contrast between the background lighting and the foreground glare source is at its maximum. In addition, the temporal contrast between the two adaptation level (before and during the glare) is very high. This results in a strong subjective perception of the headlight glare and thus in a delayed reaction time respecting the first contrast stimulus.

In contrast, for a driver with a higher adaptation luminance, the first impact of the occurring glare will be weakened. However, as his underlying adaptation level is higher, detecting the darker contrast stimuli will become increasingly difficult, yielding a higher reaction time towards the end of the TVI test.

5. Field Test

5.1 Experimental Setup

The obtained test data from the described user studies looks promising so far. But as both user studies have been executed under laboratory conditions, the next logical step was to validate the generated contrast threshold graphs in a field test.

We therefore replicated the laboratory setting on a low frequented country road. The user study setup is shown is Figure 7: the subjects were placed in a car, with an activated low beam to create an authentic adaptation luminance. After a sufficient pre-adaptation time, the subject was dazzled from a headlight on the opposing lane, 25 meter away. Exactly as in the laboratory setting, we enforced the same avoidance behavior for all subjects. Thus, they were told to fixate a given point on the right roadside to ensure comparability.

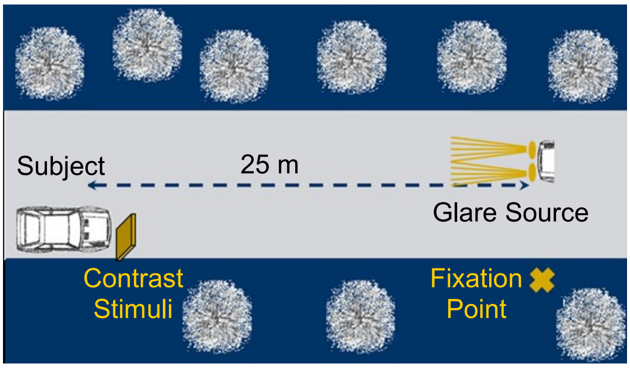

Figure 7: Setting of the field test, the subject sitting in his own car (with low beam activated), the distance to the glare source is 25m, with a fixation point at the right roadside.

Directly in front of the car, a dimmed light box was used to present homogenous, squared contrast stimuli, one per glare. The subjects were equipped with a single button to affirm when they became able to perceive the square again, and their reaction time was measured. The background illumination was kept nearly constant at 0.25 lux, mainly produced by the activated low beam.

As a field test is far more time consuming than a laboratory user study, we restricted the experiment to only one glare distance, 25 meter, and four perceivable contrast stimuli, but still tested different glare durations.

We tested 24 subjects between 20 and 35 years, with an average age of 29.5 years, again evenly distributed in male and female subjects. Further, exactly as in the previous tests, we rejected subjects with eye surgeries, glasses and a major contrast perception disability.

5.2 Results

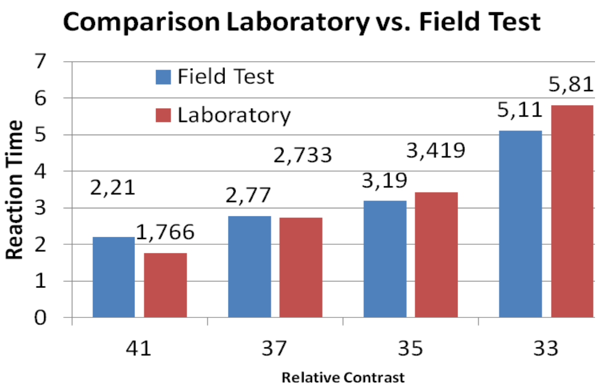

Figure 8: Comparison between the user study in the laboratory and the field test. On the x-axis: minimal distinguishable brightness, compared to a black background, on the y-axis: elapsed time after the glare

The results shown in Figure 8 demonstrate that the reaction timings between the laboratory setting and the field test are comparable.

The only noteworthy exception lies in the reaction timing to the brightest contrast stimulus. Here the subjects in the field test reacted significantly slower (note that due to limitations based on the field test the contrast stimulus ‘41’ was in the field test even slightly brighter than in the laboratory, but still the subjects reacted later). One possible explanation for this observation lies in the fundamental design of the field test. Here, the contrast stimuli were presented relatively close to the subjects, whereas the fixation point was 25 meters away. Thus, after the glare the subjects had to accommodate their eyes before being able to actively make a decision. In the laboratory though, the fixation point and the contrast stimulus were lying in the same image plain.

6. Integration into the Simulator

The addressed driving simulator has to be usable during daytime under office lighting with a standard LDR-monitor (low dynamic range monitor), even though it is supposed to show a night driving situation. However, from Chapters 3-5 only the absolute brightness values of the minimal contrast perception are known, and these are also used by the simulation software. For the final display on the monitor, these values have to be mapped to LDR. During this mapping it has to be guaranteed that the threshold between still perceivable and non-perceivable contrast is reproduced exactly as measured during the experiment.

The contrast perception on a monitor under daylight conditions is again purely subjective. We measured exemplarily for a few subjects, after a sufficient pre-adaptation phase, the minimal distinguishable contrast on the simulator monitor under office lighting. With this test data we are able to adjust the brightness histogram of the rendered images in a post-processing step: Objects with an absolute brightness being equal to the measured minimal perceivable contrast (from Chapter 3-5) are shifted in the histogram to match the minimal distinguishable contrast on the simulator monitor. Hence, it is ensured that the user is able to perceive the given contrast, but nothing below.

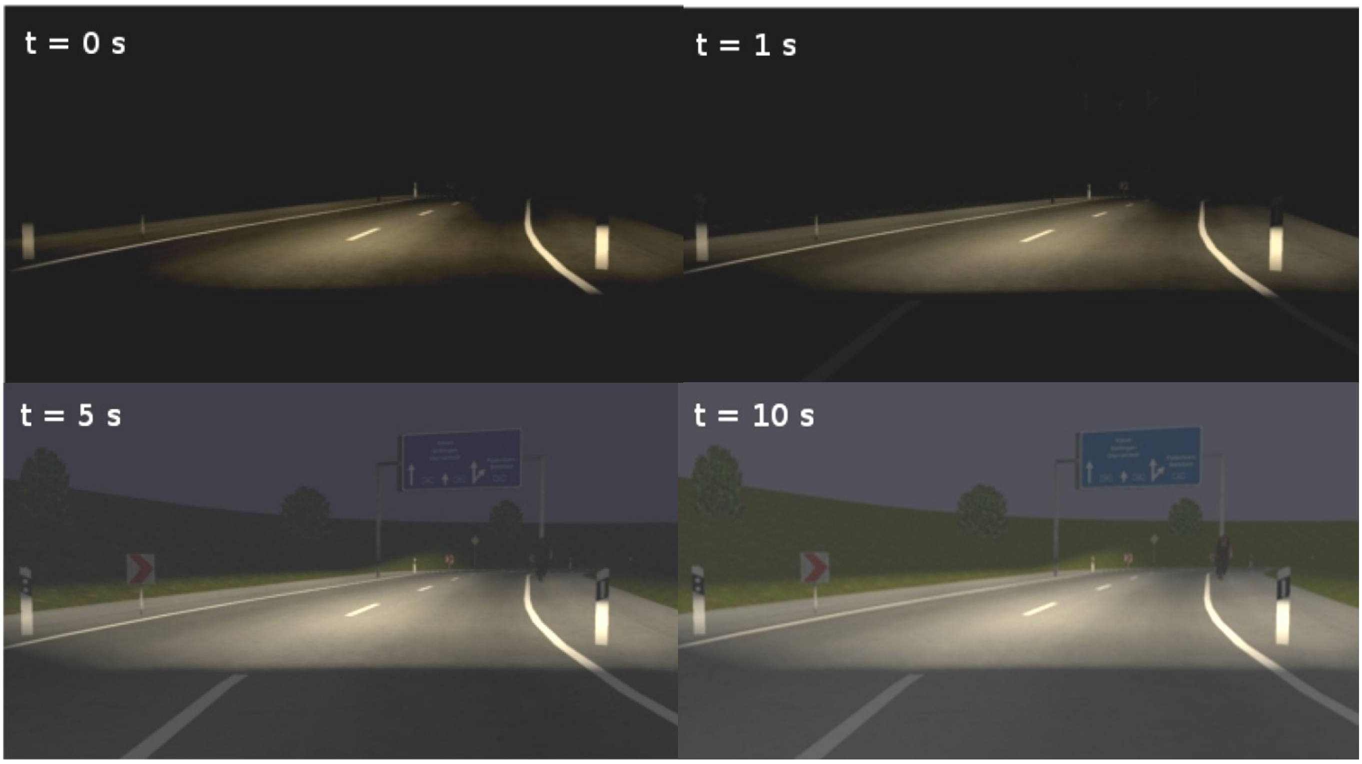

Figure 9: Screenshots of the driving simulation with integrated glare handling. After a glare, the scene is darkened abruptly. It is then relit over time, based on the measured contrast perception.

7. Conclusion

We present an explorative approach to integrate the individual re-adaptation of the human visual system after short-time glares into the visualization of a driving simulator.

This simulation is based on subjective test results, collected by several psychophysical experiments under authentic night driving conditions. Using this test data, we adjust the display contrast on a LDR-monitor under office lighting conditions to match the human contrast perception (see Figure 9) by tone mapping the minimal perceivable contrast in reality to the one on the monitor.

The modified night driving simulator provides a more realistic driving sensation in the presence of headlight glare, thus yielding a more authentic behavior of test subjects.

It is therefore the next important step towards the analysis of critical traffic situations including glare effects under defined laboratory conditions without the need to reconstruct authentic illumination conditions.

8. Outlook/Future Work

Even though the collected experimental data already yields an acceptable approximation of individual contrast perception, much more test data would be needed in order to answer more detailed questions. Reproducing a similar experiment with an increased amount of parameter values both for blending intensity and duration would enable us to draw conclusions on how to interpolate exactly between the measured perception curves.

Furthermore, we restricted the experiment to glares from static (non-moving) headlights, though oncoming traffic is normally approaching the driver continuously. An extended user study including glares from moving headlights would yield more exact results, even though many different parameter settings would have to be tested.

Finally, an extended evaluation of the implementation results by comparing human perception after glares in real traffic situations with the displayed reconstructed scenes would yield a better quality estimation of this simulation and will be our next step.

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