EXPERIMENTAL COMPARISON OF TONE MAPPING OPERATORS USING A VISUAL PERFORMANCE INDEX

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ABSTRACT

Computer graphics provide a powerful tool to study lighting and visual signalling as well as information requirements of transport and traffic, through psycho-visual experiments. However, real-world luminance dynamic range is often too high for display devices. Compression must be achieved using a so-called “tone-mapping” operator (TMO), and the question arises whether tampering with the visual cue will not alter visual performance, possibly invalidating comparisons between behaviours observed in real and simulated conditions. In the recent years, a lot of work was done in the Computer Graphics (CG) community in order to achieve a high quality display of complex images. However, the main issue in terms of image quality was the global appearance of displayed images, which leads to visual appearance image quality indexes. In this paper, we propose a visual performance image quality index, devoted to road vision applications which mainly concern CIE Division 4 issues. Our index allowed us to compare five TMOs from the CG literature, for three critical driving situations (daytime in fog, night-time with and without on-coming headlamps in the field of view).

Keywords: image display, fidelity, visual performance, driving simulation, tone mapping.

1. TONE MAPPING OPERATORS

Due to the technical limitations of image display systems, tone mapping operators (TMO) have been developed in the last 20 years in order to allow the visualization of high dynamic range (HDR) images on low dynamic range (LDR) display devices {Reinhard, 2005}. These operators are especially useful when displaying images which are described in physical units (e.g. luminance and chromaticity), coming from physically-based computer graphics (CG) models, or from calibrated cameras and video-photometers. The first approach in academic and technical papers addressed the TMO algorithmic issues: a number of operators have been proposed, based on various theoretical backgrounds (including vision science models), and with various practical goals. Then appeared, around 10 years ago, an increasing number of studies aiming at evaluating the visual quality of TMOs. Our paper addresses the second category.

2. SPECIFICITY OF ROAD IMAGES

In the practical case of road visibility studies, most TMOs from the CG literature, as well as most evaluation protocols, are inadequate. This is consistent with the idea that general purpose TMOs may be ineffective for a given application. Another point is that most TMO evaluation protocols focus on visual appearance issues (e.g. {Ledda, 2005}), which is a good choice for general purpose operators, but not for road visibility issues (e.g. road lighting or automobile lighting), where visual performance is the key factor {Brémond, 2002}.

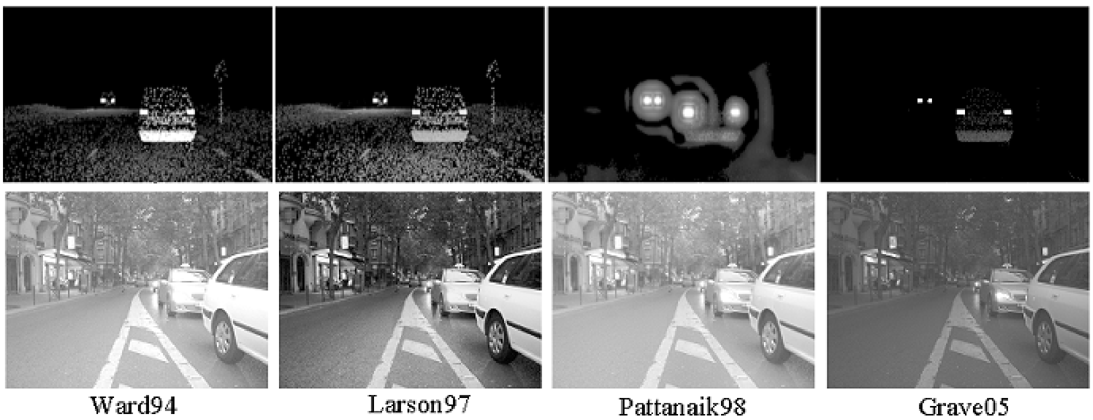

Figure 1. Daytime (1st row) and night-time (2nd row) images after processing by 4 TMOs.

In terms of input and output of the TMO, most driving simulators use large display surfaces, which results in poor luminance levels and poor luminance dynamic range, even with good display devices. Another important point is that night-time and foggy daytime road images have quite different structures (in terms of luminance histogram and spatial frequencies) than most of the images commonly used for TMO evaluations (see Fig. 1).

3. METHODOLOGY

In this paper, we propose a TMO evaluation methodology dedicated to road visibility studies. This implies to take into account a driving visual task, and to define the associated visual performance. The experimental protocol derives from usual psychophysical studies, and is inspired from previous work on the subject {Viénot, 2002}. A number of observers have to detect the position of a gap in a Landolt ring (4 possible positions, see Fig. 2), inserted in a road scene, displayed on a LDR device with a given TMO. This results in a mean performance curve. The mean performance curve of each TMO is compared with a reference mean performance curve, computed on the basis of the same experimental protocol, but with a HDR display device without TMO. The Landolt ring task was chosen as being the standard detection task, and being consistent with a detection task while driving {CIE, 1981}.

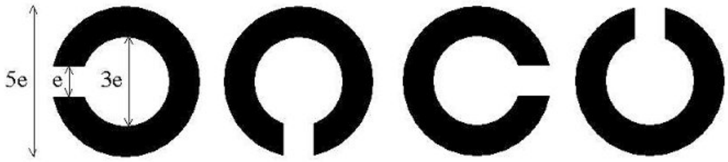

Figure 2. Gap positions in a Landolt ring.

The resulting methodology is summed up in Fig. 3. The evaluation concerns the LDR image display, which includes not only the TMO, but also the display device and the observation conditions (through the angular size of the pixels).

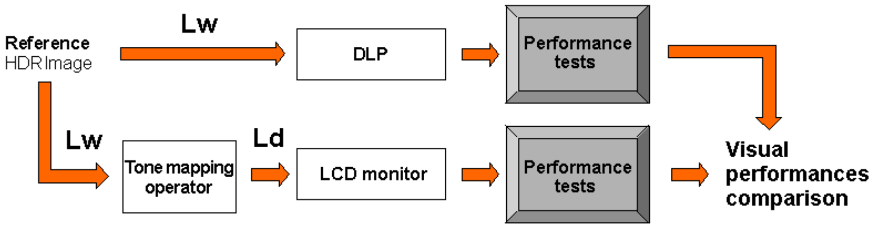

Figure 3. Methodology for a quantitative comparison of TMOs.

4. EXPERIMENT

We used this experimental protocol to compare 5 TMOs from the literature {Ward, 1996; Larson, 1997; Pattanaik, 1998; Reinhard, 2002; Grave, 2005} on a Liquid Crystal Display (LCD) device. Three driving situations were chosen: night-time country driving with direct light from an on-coming vehicle, night-time urban driving, and daytime fog with direct light from an on-coming vehicle. 10 persons participated for each of these three comparisons (see Fig. 4).

Figure 4. Photographs of the experimentation room for TMO comparisons.

Our visual performance evaluation was completed with a visual appearance evaluation of the same TMOs, on the same observers, with an experimental protocol similar to that of {Ledda, 2005}. The results of this comparison are different from those from the visual performance experiment, which is not surprising and emphasizes the need for a choice between appearance and performance indexes {Grave, 2006b}.

5. RESULTS

Fig. 5 shows the visual performance (the uncertainty estimations are only displayed for the reference situation, for easy reading) measured with the *DayFog* reference image (see the image in the upper right corner) and the 5 TMOs. The 50% detection threshold for the Landolt ring, obtained with the reference image, is for a contrast $c \subset [0.03;0.04]$. This figure allows to compare the TMOs in terms of a visual performance which is relevant in a driving condition, but the result of this comparison is restricted to the road situation of the reference situation (that is, in this example, driving through fog).

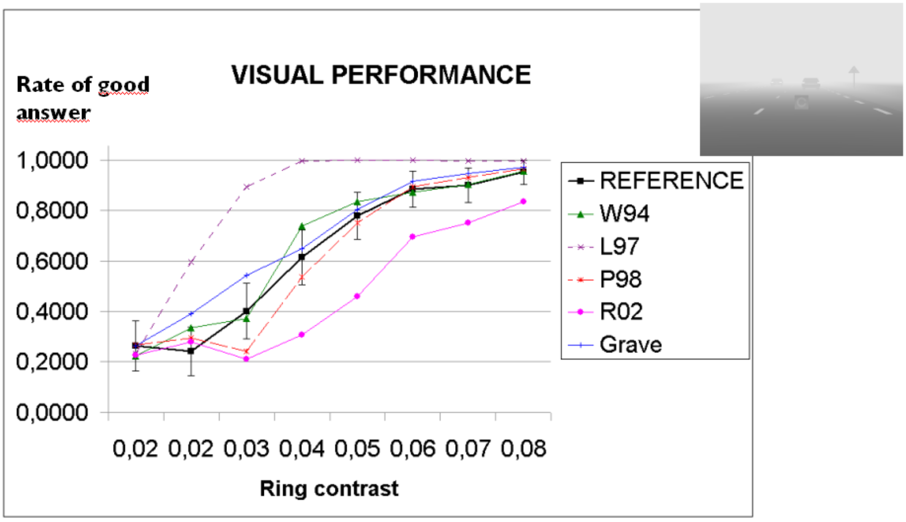

Figure 5. Comparison of the visual performances with 5 TMOs and in the reference situation, for a daylight foggy road scene.

These results are given as an example of our methodology, rather than for an exhaustive comparison, which can be found in {Grave, 2006a}. The same kind of comparison was performed for night-time images {Grave, 2006b}. The main point is that the proposed methodology gives a quantitative evaluation of any TMO for a visual task which is relevant for driving. Hence, it leads to a quality index for the TMOs, with the restrictions mentioned above.

6. CONCLUSION

We propose a TMO evaluation protocol, which is a current issue of CIE Division 8, but we build it in order to be dedicated to road visibility studies, which may lead to interesting applications for CIE Division 4 (e.g. in driving simulation applications).

The main methodological step of further work would be to adapt this methodology to changing situation, as is the case for driving simulations. Such TMO quality indexes would allow a better understanding of visual cues in driving simulators. Such an improvement may include motion detection and temporal visual adaptation issues.

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ACKNOWLEDGEMENTS

We thank very much the 30 participants of the experimental study. We also thank E. Dumont, F. Viénot, B. Péroche and J.-P. Farrugia for their help in the progress of this work.

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