ASSESSMENT OF THE VISUAL QUALITY OF TONE-MAPPED IMAGES FOR VISIBILITY EXPERIMENTS

Eric DUMONT, Roland BREMOND
Laboratoire Central des Ponts et Chaussées, Paris, France

Clotilde BOUST, Emmanuel DA COSTA, Françoise VIENOT
Muséum National d'Histoire Naturelle, Paris, France

ABSTRACT

Computer graphics provides a powerful tool to study lighting and visual signalling as well as information requirements of transport and traffic. However, real-world luminance dynamic range is often too high for display devices. Compression must be achieved using a so-called "tone-mapping" operator, 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 this paper, we present a psychometric experiment for assessing the quality of tone-mapping in terms of visual appearance and visual performance. Subjects were asked to judge on the regularity of various grey level gradations and to locate low-contrast differences, first in a reference scene and then with tone-mapped images of this scene. Four tone-mapping algorithms were tested, none of which fully succeeded in achieving the "look and feel" of the real scene.

Keywords: simulation, tone-mapping, display, psychometric experiment, visual performance.

1. INTRODUCTION

The use of driving simulation is developing to study lighting and visual signalling as well as information requirements of transport and traffic. Yet; care should be taken when running visibility experiments in virtual environments: even though physically based global illumination computations can produce accurate photometrical results, real-world luminance levels need to be compressed in order to fit within the limited dynamic range of display devices [1]. The compression is achieved by applying a so-called tone-mapping operator. Advanced techniques are usually designed on physiological grounds in order to ensure visually satisfactory results. However, the question is seldom tackled whether tampering with the visual cue might alter visual perception.

In this paper, we present an experimental method to assess the "quality" of a tone-mapping operator. Observers were first confronted with a high dynamic range environment, and then with tone-mapped images of this environment displayed on a calibrated monitor. Two types of tests were used to distinguish visual appearance from visual performance. Four classic tone-mapping algorithms were put to the test.

2. TONE-MAPPING QUALITY

A tone-mapping operator transforms real-world luminance values to make them suitable for the limited range available on a specified display device. The most obvious tone-mapping operator is the linear function which maps the maximum luminance value in an image to the maximum displayable luminance value. Such crude compression usually yields poor visual results, which raises the question of tone-mapping quality. Compressing the luminance range is usually not enough: a "good" operator should also make observers respond to simulation the same way as they would to the actual photometrical information. In fact, the relevant criterion to assess the quality may vary, depending on the visual task which is to be performed. It may be appearance if the goal is to achieve photorealism, or it may be performance if the goal is reproduce visibility.

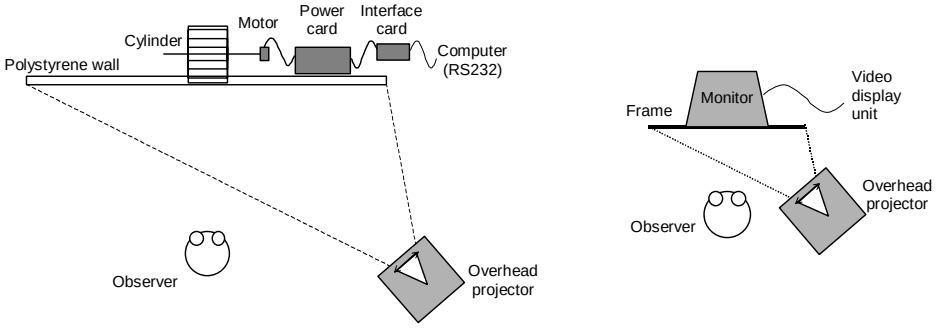
Research in the field of tone reproduction has been very active in the last few years among the computer graphics community. Advanced tone-mapping operators have been designed, based on physiological grounds in order to mimic the mechanisms of the human visual system [2]. But experimental validation of the proposed algorithms is seldom endeavoured, and usually focuses on appearance only [3,4].

3. PSYCHOMETRIC ASSESSMENT OF TONE-MAPPING

Our goal was to pick one tone-mapping operator which would reproduce both appearance and performance, in order to use driving simulation for visibility experiments. The method we designed consists in presenting observers with different psychometric tests set into one unique reference scene, first in real-world conditions – referred to as the reference situation – and then in simulation conditions – referred to as the simulated situation.

3.1 Description of the reference situation

The reference scene (Fig.1a) consisted in a diffuse white wall receiving controlled illumination from an overhead projector. A transparency was used to project square patches with various luminance (up to 800 cd.m^{-2}), which produced a medium spatial frequency noise in the periphery. The subjects sat 2 m from the wall, which filled a 44° horizontal field of view. The psychometric tests were printed with a calibrated printer on a series of plates which were attached to a rotating drum inserted in a hole at the centre of the wall (4,6° angular size).

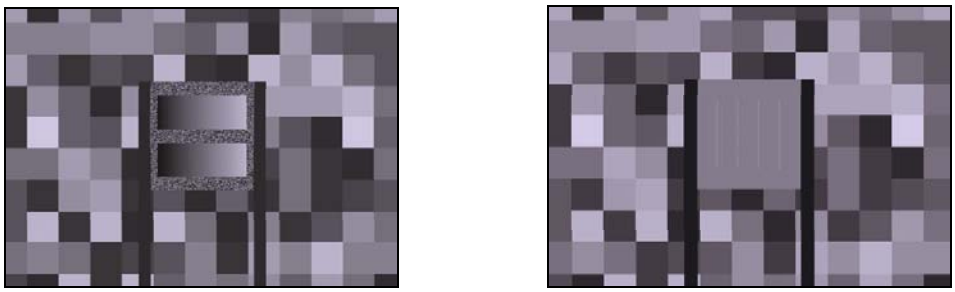


(a) (b)

Figure 1. Layout of the reference (a) and simulated (b) situations.

3.2 Description of the simulated situation

A photometer was used to measure the luminance associated with the different grey levels in the periphery and on the test plates in the reference situation, in order to produce photometric images of the reference scene for all tests. The simulated scene (Fig.1b), consisted of a CRT monitor, calibrated using the gain-offset-gamma method [5], surrounded by a frame on which the borders of the periphery were materialized using the overhead projector. The tone-mapped images of the real scene were converted into 8 bit digital images which were fed to the monitor. With the subjects sitting 60 cm from the screen, the angular sizes of the periphery, background and stimuli were the same as in the reference scene.



(a) (b)

Figure 2. Details of the simulated situation for testing visual appearance (a) and visual performance (b) reproduction.

4. TESTED TONE-MAPPING OPERATORS

Four tone-mapping operators were implemented, three of which were linear. We decided to focus on techniques which ensure the same modification of contrast throughout the scene. The first operator, referred to as “maximum”, consists in mapping the whole luminance range into the displayable range. The second operator, referred to as "mean”, compensates for the high

sensitivity of the previous operator to high singular luminance values. The third operator, referred to as “Ward’s”, introduces the contrast sensitivity of the human visual system in order to match visual performance [6]. The fourth operator, referred to as “histogram”, is not linear: its purpose is to optimise the luminance histogram in order to make maximum use of the display range [7]. It was tested because it is widely used and considered to give qualitatively good results.

5. ASSESSMENT FOR VISUAL APPEARANCE

To assess the capacity of the tone-mapping operators to reproduce visual appearance, seven subjects were presented with tests containing a pair of horizontal gradations of grey levels with different gamma values, printed over a high spatial frequency background noise (Fig.2a). For each pair they were asked to decide which gradation looked the more “regular” [8].

The results of this experiment show that observers were able to judge accurately which gradation was the best representative of an optimal gamma value. Inter-observer variability was quite high, and the question arises whether it reflects differences in scaling ability or differences in interpreting the instructions. When the preferred gamma values in the real situation are compared to the preferred gamma values in the simulated situation (Fig.3), we find that none of the tested operators performs well. The three linear operators yield preferred gamma values which are higher than those obtained with the reference scene, whereas the histogram operator yields lower preferred gamma values.

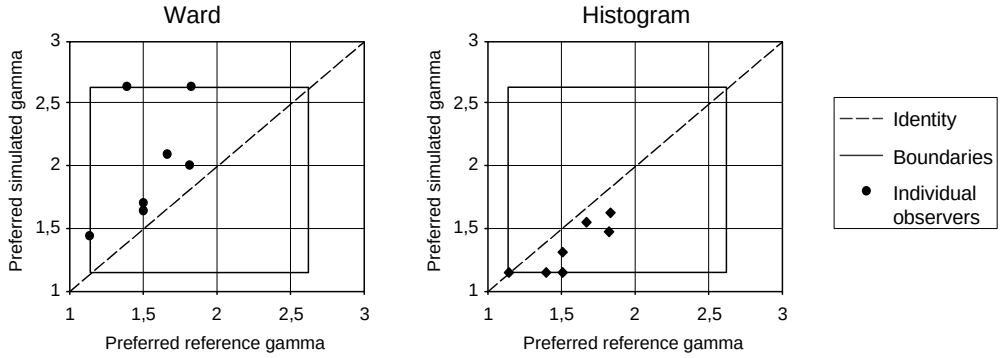


Figure 3. Preferred gamma in the simulated situation vs. preferred gamma in the reference situation, for Ward’s (left) and histogram (right) tone-mapping operators.

6. ASSESSMENT FOR VISUAL PERFORMANCE

To assess the capacity of the tone-mapping operators to reproduce visual performance, five subjects were presented with tests containing four lines printed with low positive or negative contrast over a uniform grey background (Fig.2b). In each test, one of the lines was either dashed when the others were continuous or continuous while the others were dashed. The subjects were asked to point out that particular line [9]. The time they took to respond was recorded and taken into account to evaluate the visual performance as the product of speed and accuracy [10].

The results (Fig.4) show that the three linear operators bring the visual performance down to a very low level even for the highest contrast values, whereas the histogram operator makes all contrast values clearly detectable, except for the lowest values which are mapped to zero because of quantification.

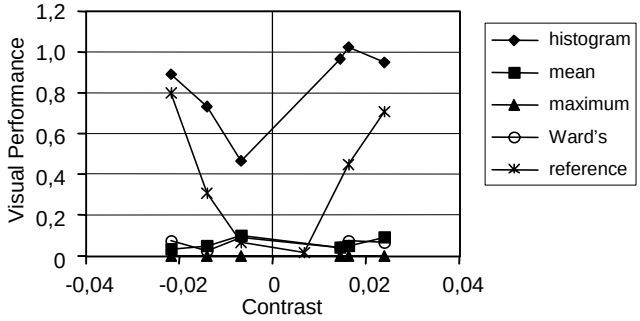


Figure 4. Comparison of visual performance in the real and simulated situations for one observer.

7. CONCLUSIONS

After our experiments, it appears that none of the four tested tone-mapping operators fully succeeds in transposing visual appearance or visual performance from the real situation into the simulation. All three linear operators, even Ward's, lead the observers to prefer higher gamma values; they also deteriorate contrast sensitivity. The histogram operator, on the other hand, leads the observers to prefer lower gamma values, and enhances contrast sensitivity (except for the quantification problem). This indicates that an intermediate tone-mapping operator might bring better results.

The presented methodology can be used to rate tone-mapping operators with various criterions: only the test plates have to be modified. In the future, we plan on adapting the layout in order to be able to study the mapping of night-time road scenes, with disability glare simulation [3].

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Authors:

Name	Eric Dumont and Roland Brémond
Affiliation	Laboratoire Central des Ponts et Chaussées
Address	58, boulevard Lefebvre – 75732 Paris cedex 15 – France
Phone	+33(0)1 4043 5349
Fax	+33(0)1 4043 5499
E-mail	dumont@lcpc.fr

Name	Françoise Viénot
Affiliation	Muséum National d'Histoire Naturelle
Address	43, rue Cuvier – 75231 Paris cedex 05 – France
Phone	+33(0)1 4079 3722

Fax +33(0)1 4079 3716
E-mail vienot@mnhn.fr