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Survey of Temporal Brightness Artifacts in Video Tone Mapping

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Abstract

High Dynamic Range video acquisition and display are now achievable thanks to recent advances in the HDR field. Tone Mapping Operators convert HDR images to Low Dynamic Range ones. However, most of these operators were designed for images and do not take into account the temporal consistency inherent in a video sequence. Consequently, the appearance of temporal artifacts impairs the quality of the tone mapped video content. We propose, in this article, to classify temporal artifacts into different types: flickering, temporal contrast and object incoherency. Then, we describe some techniques designed to solve these issues and the temporal artifacts that they generate. Finally, we conclude by differentiating the interactive and automatic tone mapping requirements.

Categories and Subject Descriptors (according to ACM CCS): I.3.3 [Computer Graphics]: Picture/Image Generation—Display algorithms

1. INTRODUCTION

High Dynamic Range (HDR) imagery is becoming widely known in both the computer graphics and image processing communities. Albeit few commercial displays exist, benefits from using HDR technology can already be appreciated thanks to Tone Mapping Operators (TMOs). Indeed, TMOs reproduce the wide range of values, available in an HDR image, on an LDR display.

There are two main types of TMO: global and local operators. Global operators use characteristics of an HDR image to compute a monotonously increasing tone map curve for the whole image. However, they usually fail to reproduce finer details contained in HDR images. On the contrary, local operators tone map each pixel based on its spatial neighborhood. These techniques increase local spatial contrasts, thereby providing more detailed images.

Naively applying a TMO to each frame of an HDR video sequence leads to temporal artifacts. In this work, we propose to investigate the different types of temporal artifacts along with their main causes. We distinguish three main types of temporal artifact: flickering, temporal contrast and object incoherency. Their descriptions and sources are detailed in section 2. Some existing techniques aim at reducing these artifacts by extending TMOs to the temporal domain. However they also entail three other types of temporal artifact: ghosting, temporal contrast adaptation and trade off between spatial contrast and temporal object coherency. These techniques and their associated artifacts are presented in section 3. Section 4 concludes this article.

2. Temporal Artifacts

In this section, we describe temporal artifacts encountered when tone mapping HDR video sequence. Note that we voluntarily focus on artifacts related to the brightness and ignore those concerning color. Furthermore we also dismiss temporal noise because we consider that a TMO only amplifies these artifacts and do not creates them. We propose to categorize temporal artifacts into three categories: flickering, temporal contrast and temporal object incoherency. This section provides a description of those artifacts along

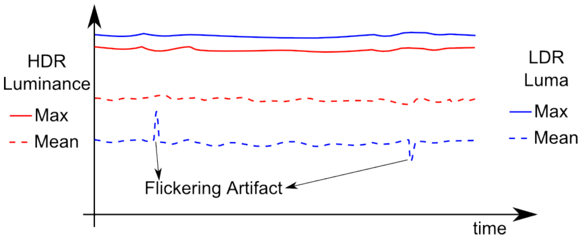


Figure 1: Illustration of two global flickering artifacts. The overall brightness in the HDR sequence is stable over time while two variations occur in the LDR sequence.

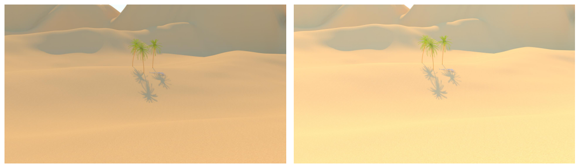


Figure 2: Example of global flickering artifacts due to the use of the 99% percentile (Farbman et al. [FFLS08], multi-scale operator).

(a) Zoom on a portion of the computed base layer (using the Bilateral Filter (BF) [DD02]) of 3 successive frames.

(b) Corresponding tone mapped results with a local flickering artifact.

Figure 3: Example of local flickering artifacts when applying an edge-aware TMO to 3 consecutive frames.

with some examples. Note that, in this section, all the results are provided using TMOs that do not handle time-dependency.

2.1. Flickering Artifacts (FA)

The main type of temporal incoherency that has been investigated is flickering artifacts (FA). A flickering artifact occurs when the mapping changes abruptly in successive frames. Say similar HDR luminance values in successive frames are mapped to different LDR values. These artifacts occur because TMOs adapt their mapping to the HDR content. Consequently small changes in the content may alter greatly the tone mapping. These artifacts can either be global or local, usually depending on the type of TMO used.

Global flickering artifacts are characterized by a change of the overall brightness of a tone mapped video content. An analysis of the geometric mean over time is usually sufficient to detect those artifacts. Note that the geometric mean is commonly considered as an indication of the overall brightness of an image. Figure 1 illustrates the occurrence of two global flickering artifacts by plotting the geometric mean of both the HDR and LDR sequences. These artifacts appear because one of the TMO's parameters, that adapts to the content, varies over time (for example a normalization factor such as the 99^{th} percentile). To sum up, global flickering artifacts mostly occur with TMOs that rely on content adaptive parameters that are unstable over time. Figure 2 illustrates such an artifact occurring in two successive frames of a tone mapped video sequence. The overall brightness has changed because the relative area of the sky in the second frame is smaller, hence reducing the chosen normalization factor (99^{th} percentile).

Local flickering artifacts correspond to the same phenomenon as its global counterpart but on a reduced area. They appear mostly with local TMOs, say TMOs that adapt the mapping of a pixel to its spatial neighborhood. Small changes of this neighborhood, in consecutive frames, may result in a different mapping that causes this kind of artifact. This is a common artifact occurring with edge-aware TMOs, say TMOs that decompose an HDR image into a base layer and one or more detail layers. As each layer is tone mapped independently, a difference in the filtering in successive frames results in flickering artifacts. An example is illustrated in Figure 3a that represents a zoom on a portion of the computed base layer (using the Bilateral Filter (BF) [DD02]) of 3 successive frames. Note how the edges are less filtered out in the middle frame compared to the other two. Applying the BF operator results in a local flickering artifact (on the streetlight) in the tone mapped result (Figure 3b).

2.2. Temporal Contrast Incoherency (TCI)

A second type of temporal artifact is the Temporal Contrast Incoherency (TCI). It appears when a change of illumination condition in the HDR sequence is not preserved during the tone mapping. Consequently, temporal information (i.e. the change of condition) is lost, which changes the perception of the scene (along with its artistic intent). Figure 4 illustrates a TCI artifact by plotting the geometric mean of both the HDR

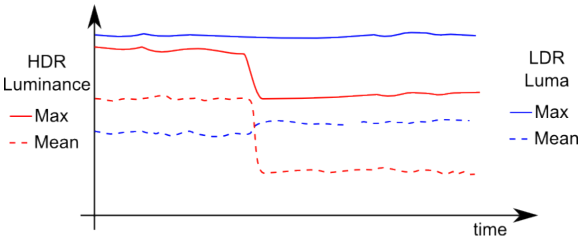
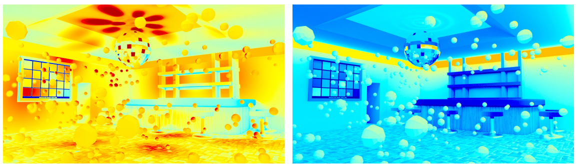


Figure 4: Illustration of a temporal contrast incoherency. The change of illumination condition (represented by the mean value) in the HDR sequence is not preserved in the tone mapped result.



(a) False color luminance, red correspond to $L_{V,max}$ and blue $L_{V,min}$

(b) TMO applied: Reinhard et al. [RSSF02]

Figure 5: Example of a temporal contrast incoherency when a change of illumination occurs. Both frames appear at the same level of brightness although the false color representation indicates otherwise.

and LDR sequence. Note that although the geometric mean greatly varies in the HDR sequence, it remains stable in the LDR one. This is due to the fact that a TMO searches for the best exposure of the content to tone map. As it has no information from temporally close frame, the change of illumination is simply dismissed and the best exposure is defined independently (usually in the middle of the available range).

Figure 5 illustrates a TCI occurring in 2 consecutive frames of a tone mapped video sequence. Figure 5a displays the HDR luminance of these frames in false color. The transition of illumination conditions occurs when the disco ball light source is turned off. When applying a TMO, this change of illumination condition is lost (Figure 5b).

2.3. Temporal Object Incoherency (TOI)

Temporal Object Incoherency (TOI) occurs when an object's brightness, stable in the HDR sequence, varies

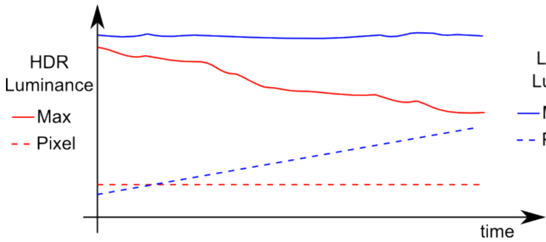


Figure 6: Illustration of temporal object incoherency. A pixel's value that is constant in the HDR sequence varies greatly in the LDR one.

in the LDR one. These artifacts resemble those that occur when commercial cameras adapt their exposure to the content during a recording [FL11]. Figure 6 plots the HDR and LDR value of a pixel. Note that the HDR pixel's value is constant over time while the recorded content changes. As the TMO adapts to the content, the LDR pixel's value changes, resulting in a TOI artifact. Figure 7 illustrates visually such an artifact. When looking, at the false color representation of the HDR luminance (Figure 7a), the level of brightness of the downside of the bridge appears stable over time. However, after applying a TMO (Figure 7b); the bridge, that appears relatively bright at the beginning of the sequence, is almost dark at the end. The temporal coherency of those pixels in the HDR sequence has not been preserved in the LDR one.

3. Temporal Artifacts caused by Video TMOs

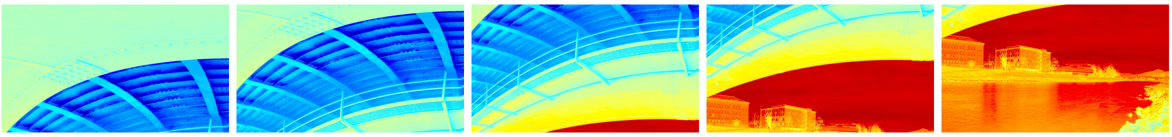
In this section, we describe some solutions that aim at reducing the temporal artifacts presented in the previous section. Note that we do not intend to be exhaustive in the list of techniques provided here as other surveys [BTBC13] and subjective evaluation [EWMU13] already cover it. We present those algorithms only to describe how they can generate new temporal artifacts not anticipated before. We choose three techniques:

- temporal filtering that is a common technique to extend global operators to the temporal domain,
- an extension of a local TMO relying on motion estimation,
- a generic solution to reduce both TCI and TOI artifacts through a post-processing operation.

The corresponding temporal artifacts described are: temporal contrast adaptation, ghosting artifacts and the trade off between spatial contrast and temporal object coherency.

3.1. Temporal Contrast Adaptation

A generic solution, usually considered to reduce global flickering artifacts, performs temporal filtering



(a) False color luminance, red correspond to $L_{V,max}$ and blue $L_{V,min}$

(b) TMO applied: Reinhard et al. PTR [RSSF02]

Figure 7: Example of temporal object incoherency, the pixels values of the downside of the bridge are similar in the HDR sequence while greatly varying in the LDR one. False color luminance (a) and tone mapped frames (b) 10, 50, 100, 150 and 200 of a sequence.

[BTBC13, DD00]. Depending on the used TMO, the filter is either applied to the computed tone map curve [MDK08] or to the variable that adapts the mapping to the image [RIH04, KRTT12]. Examples of variables are the geometric mean of an image (which is an indication of its overall brightness), its maximum or minimum value etc.

Temporal filtering efficiently reduces global flickering artifacts. However, when a change of illumination occurs as presented in section 2.2, it is also filtered temporally. Consequently, the resulting mapping does not correspond to any of the conditions but rather to a transition state. We refer to this artifact as temporal contrast adaptation.

Figure 8 illustrates how the temporal filtering of the tone map curve causes this artifact during a change of illumination. Note how the tone map curve, plotted on top of the histograms, shifts from the first illumination condition (frame 130) toward the second state of illumination (frame 150, see Figure 5 for the false color luminance). As the tone map curve has anticipated this change of illumination, frames in the transition are tone mapped incoherently.

3.2. Ghosting Artifacts

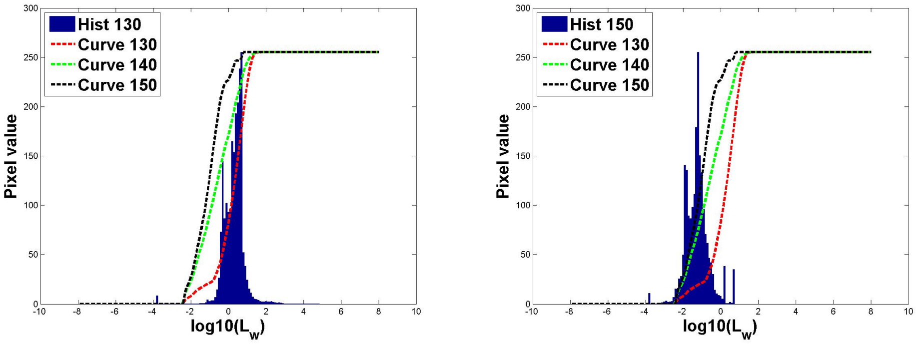
Few local TMOs have been adapted to cope with HDR video sequences, the Gradient Domain operator (GD) [FLW02] is one of them. This operator compresses the dynamic range of an HDR image by attenuating the spatial gradient depending on its intensity. A spatially variable mapping function attenuates large gradients at various scales while preserving fine details. Applying this TMO to a video sequence results in local flickering artifacts, since the attenuation of the gradient changes from frame to frame. Lee et al. [LK07] proposed a technique to extend this TMO to video tone mapping. The authors rely on a pixel-wise motion estimation computed on the original HDR sequence. This motion field is used as a constraint for the temporal coherence between the LDR frames.

This solution efficiently reduces local flickering artifacts due to the used TMO. However, it relies on a motion estimation which is not robust to change of illumination conditions and object occlusions. Consequently, ghosting artifacts appear when the quality of the motion estimation is not sufficient. Figure 9 illustrates a ghosting artifact in two successive frames resulting from the application of Lee et al. operator [LK07]. These artifacts prove that pixel-wise temporal filtering to reduce local flickering artifacts only works with efficient motion estimation. Incoherent (or bad match) motion vector should be accounted for to prevent ghosting artifacts.

3.3. Trade off between Spatial Contrast and Temporal Object Coherency

The main issue with the two mentioned techniques (and most others that reduce temporal artifacts) is the use of a temporal window with small size. Indeed, as described in section 2.3, to preserve an object brightness coherency over a whole sequence, more than just the temporal neighborhood is required. That is why, Boitard et al. [BCTB13] developed a method which adapts to any TMO through a post-processing operation and relies on a video analysis performed prior the tone mapping. This technique computes constant luminance zones throughout the video to preserve the relative HDR brightness level between those zones in the tone mapped LDR sequence. The post-processing consists in scaling each tone mapped value with respect to an anchor value (usually corresponding to the brightest zone/object in the whole video).

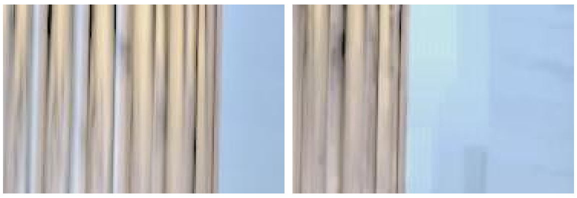
(a) Tone mapped result (frame number 130, 140, 149 and 150) using Mantiuk et al. operator [MDK08] with the temporal filtering active (pfsTMO implementation [GK]).



(b) Histograms of frames 130 (left) and 150 (right) along with the corresponding tone map curve for frames 130, 140 and 150 (the tone map curve of frame 149 is not plotted as it is close to that of frame 150).

Figure 8: Example of temporal filtering of the tone map curve when a change of illumination occurs. The anticipation of this change causes a temporally incoherent tone mapping.

(a) Tone mapped frames (Lee et al. operator [LK07])



(b) Zoom for better visualization of a ghosting artifact (top left-hand corner of the frame).

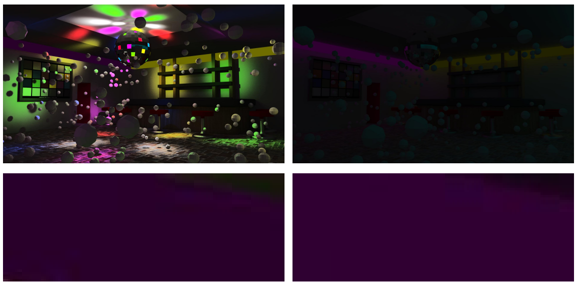
Figure 9: Ghosting Artifacts appearing on two successive frames. It is most noticeable around the two forefront columns. The motion between the two frames was too great for the motion estimation capabilities.

However, preserving both the temporal and spatial contrast while ensuring the coherency of each object still is a hard problem. In other words, consider an object of dim appearance in both a dark and bright scene. Temporal object coherency requires that this object keeps the same level of brightness after tone mapping. However, by doing so, very few spatial contrast will be noticeable when rendering the dark scene. In [BCTB13], a user-defined parameter (ζ) balances this trade-off. Figure 10 illustrates the trade off between spatial contrast and temporal object coherency with the use of ζ. In Figure 10a, the coherency of the violet light is preserved in both frames, however the second frame is too dark to distinguish anything. In Figure 10b, both frames are coherently exposed however the violet light intensity is different.

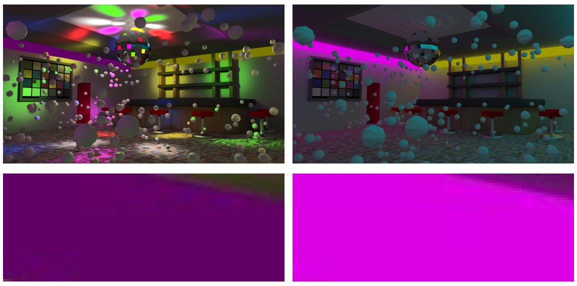
4. Conclusion

We first described three types of temporal artifact that appear when applying naively a TMO to each frame of an HDR video sequence: flickering artifacts, temporal contrast and object incoherency. The flickering artifacts have been described both globally and locally. Then, we presented some techniques that aim at reducing one of these artifacts and that can generate other kinds of unexpected artifact: temporal contrast adaptation, ghosting artifacts and the trade off between spatial contrast and temporal object coherency.

Among those artifacts, we believe that some are of more importance on the subjective quality than others. In particular, ghosting artifacts should be prevented as shown in [EWMU13] as they impairs greatly



(a) Tone mapped result (top-row) with Boitard et al operator and $\zeta = 0$ [BCTB13]. Bottom-row is a zoom on the violet light on the left wall.



(b) Tone mapped results (top-row) with Boitard et al operator and $\zeta = 0.2$ [BCTB13]. Bottom-row is a zoom on the violet light on the left wall.

Figure 10: Example of trade off between spatial contrast and temporal object coherency with the use of ζ. The frames used are the same as in Figure 5.

the subjective quality. Flickering artifacts (both global and local) should also be kept to a minimum. The temporal contrast incoherency can be considered as less important on the subjective quality however it is the most important artifact for both narrative and artistic intent. As they also generate temporal contrast adaptation artifacts, the TMO should verify that no change of illumination occurs in the upcoming HDR frame. Furthermore, as shown in section 3.3, making a compromise between the spatial contrast and the temporal object coherency is a challenging task. All these temporal artifacts led us to believe that video tone mapping is a field that still requires further research.

To conclude, we believe that all these artifacts could be avoided by performing a user-controlled frame by frame tone mapping. Although it requires much man power and available time, we believe that the current set of techniques along with their parameters are enough to achieve such a goal. However many applications such as real-time tone mapping, broadcast, display-built TMO etc., require a fully automatic or at least a semi-automatic video tone mapping. We mean by semi-automatic the tuning of the TMO's parameters for one frame and their direct application to the rest of the sequence. For those applications, the current state of the art technique are not sufficient.

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