International Journal of Latest Engineering and Management Research (IJLEMR)
ISSN: 2455-4847
www.ijlemr.com || Volume 02 - Issue 10 || October 2017 || PP. 41-44

3D Stereoscopic Video production using Foundry Nuke

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Abstract: Recent subjective studies showed that current tone mapping operators either produce disturbing temporal artifacts, or are limited in their local contrast reproduction capability. We address both of these issues and present an HDR video tone mapping operator that can greatly reduce the input dynamic range, while at the same time preserving scene details without causing significant visual artifacts. To achieve this, we revisit the commonly used spatial base-detail layer decomposition and extend it to the temporal domain. We achieve high quality spatiotemporal edge-aware filtering efficiently by using a mathematically justified iterative approach that approximates a global solution. Comparison with the state-ofthe- art, both qualitatively, and quantitatively through a controlled subjective experiment, clearly shows our method's advantages over

previous work. We present local tone mapping results on challenging high resolution scenes with complex motion and varying illumination. We also demonstrate our method's capability of preserving scene details at user adjustable scales, and its advantages for low light video sequences with significant camera noise.

Keywords: Video Tone Mapping, Edge-Aware Video Filtering

I. INTRODUCTION

New video technologies keep improving the quality of the viewing experience: display resolutions are moving up from HD to 4K,frame rates in cinemas are increasing to 48fps and beyond, and stereoscopic 3D is introducing depth as an additional dimension. While through these advances the fidelity of the content in terms of spatial and temporal resolution and depth has been gradually increasing, the dynamic range aspect of video has received little attention until recently. However, this can be expected to change quickly as modern high-end cameras (such as the Red Epic Dragon, SonyF55 and F65, and ARRI Alexa XT) now can natively capture High Dynamic Range (HDR) video up to 14 f-stops. Creatives are highly interested in HDR video because it allows them to show more visual detail and extend the limits of artistic expression. Consequently, the entertainment industry is working towards HDR video pipelines for delivering content to the end user, including related distribution standards (MPEG and JPEG). However, the final element of the pipeline is slightly lagging behind: despite the existence of a small number of products and impressive research prototypes, consumer level HDR display technology is not yet on the horizon. Still, in the absence of displays that are capable of fully reproducing the captured dynamic range, tone mapping of HDR video provides a means of visualization and artistic expression. More specifically, it may be desirable to reduce the dynamic range of captured HDR content while both maintaining most of the visual details and not hampering the picture quality by introducing visible artifacts. Recent subjective experiments on the state-of-the-art in HDR video tone mapping [Eilertsen et al. 2013; Petit and Mantiuk 2013] revealed that none of the current methods (including a camera response curve) could achieve both goals at the same time. In this work we propose a new HDR video tone mapping operator (TMO) to help close the gap between the captured dynamic range and displayed dynamic range. We build upon prior work in image tone mapping that utilize base and detail layers. Such a decomposition allows compressing the base layer's dynamic range while the local contrast remains intact in the detail layer. Different from prior work, our decomposition utilizes spatiotemporal filtering through per-pixel motion paths. This way, our method enforces temporal coherence and significantly reduces temporal artifacts such as brightness flickering and camera noise without introducing ghosting. As a result, we enable local HDR video tone mapping that can be art-directed without introducing visually significant artifacts. The two main contributions of our work are the following: A temporally coherent and local video tone mapping method

that can maintain a high level of local contrast with fewer temporal artifacts compared to the state-of-the-art (validated by a subjective study). A practical and efficiently parallelizable filtering approach specifically designed for tone mapping, that reduces halo artifacts by approximating a global solution through iterative application (with a formal analysis of the filter's halo reduction property). We show our method's advantages both qualitatively through examples (Sections 5.1 and 5.4), and quantitatively through a controlled subjective study (Section 5.2). We also demonstrate that our method allows creative control over spatial and temporal contrast (Section 5.5) through a simple user interface (Section 5.3). Finally, due to temporal filtering we show that our method works especially well for low light shots with significant camera noise (Section 5.6). Next section continues with a brief discussion of the related work.

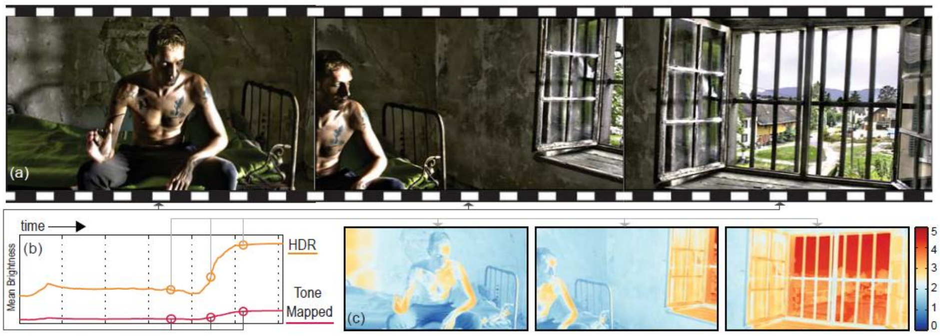

Figure 1: *Our method allows local tone mapping of HDR video where the scene illumination varies greatly over time, in this case more than 4 log_{10} units (c). Note that our method is temporally stable despite the complex motion of both the camera and the actor (b), and the resulting tone mapped video shows strong local contrast (a). The plots show the logmean luminance of the HDR video and the mean pixel values of the tone mapped video.*

Visual Trade-offs in Local Video Tone Mapping

Since HDR tone mapping often significantly reduces the input dynamic range, some of the scene contrast is inevitably lost during the process. As such, local image tone mapping involves a visual tradeoff between fine and coarse scale contrast. If coarse scale contrast is emphasized, the luminance difference between large image regions, as well as highlights and shadows become more pronounced at the cost of the visibility of the fine scale details. If, on the other hand, fine scale contrast is emphasized, the relative reduction of coarse scale contrast often results in a “flattening” effect. Additionally in local video tone mapping, another similar trade-off exists between spatial and temporal contrast. Consider an HDR video clip that transitions from bright sunlight to a darker hallway, and therefore has strong temporal contrast (Figure 2). One strategy for tone mapping such a clip is to utilize the full dynamic range independently at every video frame, such that both frame (a) and frame (b) have sufficient brightness to reproduce most of the scene details. This way one can maintain the tone mapped video’s spatial contrast, with the side effect of reducing the sensation that the hallway is much darker than the outside. Another (complementary) strategy for tone mapping the same video is maintaining a certain amount of the temporal contrast at the cost of less visible spatial details during the hallway part. In our view, the aforementioned trade-offs are context dependent and ultimately artistic decisions, and no tone mapping strategy is inherently better than others in all possible scenarios. It is therefore desirable that the tone mapping algorithm offers the required artistic freedom by providing explicit control over spatial contrast at different scales, as well as temporal contrast. Importantly, the tone mapping method should maintain a consistent level of image quality, since the artistic freedom makes little practical sense if a certain set of edits create visually noticeable artifacts. In that sense, video tone mapping is especially challenging because the temporal dimension emerges as a new source of artifacts. In fact, high temporal frequency artifacts such as brightness flickering, camera noise, as well as any temporal inconsistencies of the TMOs are immediately noticeable because of the human visual system’s proper ties. In particular, Eilertsen et al. [2013] noted that even very small amounts of ghosting and flickering in the tone mapped HDR videos are unacceptable in practice.

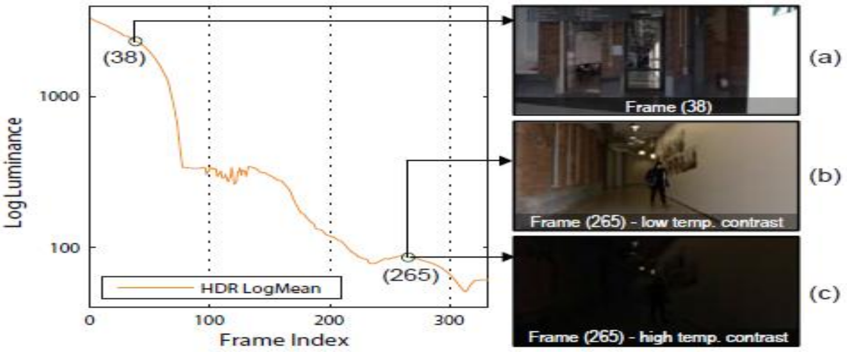

Figure 2: *The visual trade-off between emphasizing spatial contrast (a, b) and temporal contrast (a, c). While in both settings frame 38 remains the same (a), frame 265 can be adjusted to either maintain spatial (b) or temporal contrast (c).*

II. TONE MAPPING PIPELINE

Recent subjective studies revealed that local TMOs (which usually maintain local contrast) are temporally unstable [Eilertsen et al. 2013]. Similarly, na¨ıvely applying image TMOs to individual video frames has been found to produce strong temporal artifacts [Eilertsenet al. 2013; Boitard et al. 2014a]. Global TMOs with relatively simple processing steps are found to be less susceptible to temporal artifacts, however they lack the contrast reproduction capabilities of local operators. The temporal instability of local TMOs underlines the necessity of temporal filtering for local video tone mapping. Since filtering in the temporal domain is notably more challenging than in the spatial domain, one can assume that the scene is static and filter through a straight line in the temporal dimension [Bennett and McMillan 2005]. However this approach generates strong ghosting artifacts as in practice the static scene assumption rarely holds. In contrast, Lang et al. [2012] propose a general purpose approach that filters through each pixel’ s path over time. The downside of their method is that the path computation is performed globally over the whole video sequence, which therefore needs to be kept in memory. As such, this approach becomes infeasible for longer video sequences at high resolutions. Similarly, for such sequences Ye et al.’ s [2014] method is prohibitively expensive as it is reported to require over a minute to process a 800 × 600 frame (moreover this method is not designed for tone mapping). Our approach, similar to Durand and Dorsey [2002] and many others, uses the idea of decomposing each frame into a base and detail layer by utilizing an edge-aware filter, but with the key difference of filtering in the temporal dimension by utilizing optical flow. The main processing steps of our method are depicted in Figure 3. In our approach, the base layer is obtained by edge-aware spatiotemporal filtering of an HDR video cube consisting of a center frame and a number of its temporal neighbors. This way, we reduce the effect of illumination changes over time and enforce temporal coherence in the base layer. The computation of the detail layer also involves filtering the input HDR sequence, but only in the temporal dimension. This way we effectively reduce temporal artifacts with low amplitude and high temporal frequency (such as camera noise and brightness flicker) without sacrificing spatial resolution. While still retaining a contrast reproduction capability comparable to Durand and Dorsey’ s image tone mapping framework, we also suppress halo artifacts commonly observed in such frameworks through our shift-variant filter that approximates a global solution. The spatiotemporal filtering is performed on a temporal neighborhood and uses forward and backward optical flow estimates to warp each frame’ s temporal neighborhood, such that their pixels are aligned on a straight line in time dimension. The temporal filtering proceeds only if the temporal alignment is predicted to be reliable. This way temporal consistency is enhanced while minimizing ghosting. While our method is not bound to a specific optical flow algorithm, in our implementation we use Zimmer et al. s approach [2011]. We mostly used the method’ s standard parameters and spent no special effort for fine-tuning the optical flow results, but rather focused on developing measures that detect optical flow errors (discussed in Section 4.3). Our method’ s spatiotemporal filtering process is depicted in Figure 4. For a single input HDR frame It in the log domain (a), we consider a number of consecutive past and future frames as the temporal neighborhood (b). The optimal size of the temporal neighborhood depends on the content and flow quality, however we empirically found that 10 frames in each direction works well in our implementation. Next, for each frame in the temporal neighborhood we compute a permeability map (c) which controls the spatial diffusion between neighboring pixels. The permeability map is used as an input to the spatial filtering process (d) and prevents filtering across strong image edges. Specifically, the spatial part of our filtering involves iterative application of the shift-variant spatial filter hs to the frame J(k) t , where k denotes the iteration, and J(0) t = It.

The (k + 1)th iteration result is computed as:

$$J_t^{(k+1)} = J_t^{(k)} * h^s + \lambda \left(I_t - J_t^{(k)} \right), \tag{1}$$

III. CONCLUSION

We presented a local HDR video tone mapping method, that can significantly reduce the input dynamic range while preserving local contrast. Our key difference is the use of a temporal filtering through per-pixel motion paths, which allowed us to achieve temporal stability without ghosting. We formulated an edge-aware filter that is applied by iterative shift-variant convolutions, and shares the same halo suppression properties with the WLS filter, which allowed us to efficiently realize our tone mapping framework. We presented qualitative and subjective comparisons to the state-of-the art which resulted favorably for our method. We showed results produced with various tone mapping configurations from challenging HDR sequences, and presented a simple yet effective user interface. Finally we noted the advantage of our method in low-light HDR sequences.

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