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Citation for published version (APA):
Cvetkovic, S. D., Klijn, J., & With, de, P. H. N. (2009). Adaptive tone-mapping transfer functions for high dynamic range video cameras. In *Proceedings of the International Conference on Consumer Electronics 2008, ICCE 2008, 9-13 January 2008, Las Vegas, Nevada* Article 6.3-5 Institute of Electrical and Electronics Engineers. https://doi.org/10.1109/ICCE.2008.4587909

DOI:
10.1109/ICCE.2008.4587909

Document status and date:
Published: 01/01/2009

Document Version:
Publisher’s PDF, also known as Version of Record (includes final page, issue and volume numbers)

Please check the document version of this publication:

• A submitted manuscript is the version of the article upon submission and before peer-review. There can be important differences between the submitted version and the official published version of record. People interested in the research are advised to contact the author for the final version of the publication, or visit the DOI to the publisher's website.
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Adaptive Tone-Mapping Transfer Functions for High Dynamic Range Video Cameras

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Abstract- **For real-time imaging with digital video cameras, good tonal rendition of video is important to ensure high visual comfort for the user. Except local contrast improvements, High Dynamic Range (HDR) scenes require adaptive gradation correction (tone-mapping curve) that should enable good visualization of details at lower brightness. We discuss how to construct and control optimal tone mapping curves, which enhance visibility of image details in the dark regions while not excessively compressing the image in the bright image parts. The result of this method is a 21 dB expansion of the dynamic range. The new algorithm was successfully evaluated in HW and is suited for any video system performing HDR video compression.**

I. INTRODUCTION

In a digital camera system, gamma correction is often performed as a compensation of the CRT transfer function. It is observed that the *standard* gamma correction (as in Fig. 1) is often not sufficient to improve visibility of dark image details due to the compression of the dynamic range of the image sensor to the range of the display device. Simply, a high dynamic range input signal from the sensor exceeds the capabilities of display devices with several orders of magnitude. Therefore, steeper gamma functions have been used (Fig. 1, *extended range*). The problem of this approach is that it introduces extreme compression of a large portion of the input signal and makes the resulting image very pale. Even the modified tonal rendition of gamma with limited amount of compression in high luminance does not satisfy our requirements (Fig. 2, smart extended range Gamma). Thus, we propose a segmented tone-mapping function based on splines, to control individual segments in the function, together with a control algorithm for their selection. It will become clear that the applicability of our technique is increasing with the new multiple-exposure time sensors since we can achieve higher SNR that is beneficial in the process of the HDR expansion.

II. AN IMPROVED TONE-MAPPING METHOD

A. *Improved tone-mapping curves*

Several authors studied HDR compression problems [1,2,3], but only up to 10 dB of expansion of the dynamic range was achieved. For further improvement, we split a gamma transfer function into two functions, the so-called knee and gamma functions. The *knee* transfer function is stretching the black interval to enhance visibility in darker parts of the scene. It is especially useful for the HDR scenes with sufficient Signal-to-Noise Ratio. As the optimal amount of stretching is scene, light and sensor dependent, a flexible circuit was designed using quadratic splines. It starts with splitting the luminance input range into n sections. Each section has its 'core' spline part, while the spline tails extend to the neighboring sections.

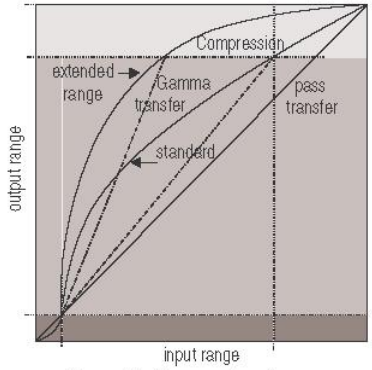

Figure 1: Gamma functions

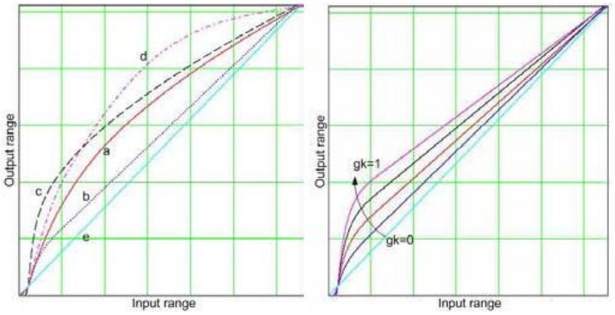

Figure 2 (left): Tone-mapping functions: a) Gamma; b) Knee; c) Gamma and Knee together; d) smart extended range Gamma; e) linear transfer function. Figure 3 (right): Example set of knee transfer functions for several values of g_k, ranging from 0 to 1.

The shape of the function guarantees a smooth transition between consecutive sections (continuous first derivative). Additionally, we found a relationship between n section parameters $c_1, c_2, .., c_n$, which ensures a desirable shape of the overall knee transfer function. It relates all section parameters to a one control parameter g_k (x is the input range variable, h_i ($i=1..n$) is a set of functions):

$$f_{knee}(x) = f_{knee}(x, c_i \mid c_i = h_i(g_k), i = 1..n) \qquad (1)$$

As a result, the shape and extent of the overall knee function can be controlled with that parameter g_k (see Fig. 3). As noted in Fig. 2, the knee transfer function (as well as the overall transfer function (knee + gamma)) can be steeper than the standard gamma function in the beginning of the input range while introducing less compression in the last part of the input. As a final result, we can reproduce the objects with dynamic range wider than one of the standard display and still do not significantly deteriorate gradation in the bright area.

B. *Control algorithm to determine the optimal g_k*

A control strategy is to relate the image median value after the knee-tone mapping curve to the mean video level after the

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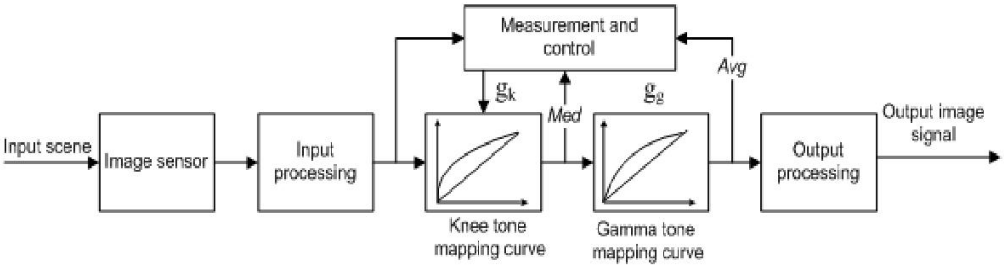

Figure 4: Dynamic control of knee and gamma functions to optimize the displayed image

gamma output (see Fig.4, *Med* and *Avg*). We do this by controlling parameter g_k of the f_{knee} function. Hence we couple the knee transfer function gain to the output video level. Increasing parameter g_k leads to a non-linear growth in the output video level and the *Med* value. Because of the chosen knee shape, the *Med* increase is larger than the *Avg* increase for the majority of the images. By such an action, the image histogram is redistributed to an improved version. The idea behind this control is that when the customer sets a certain Wanted Video Level (WVL) from the camera, we will only optimize the output video image around that level and not change it too much. Like this, we do not over-compensate the video signal, especially at a low WVL, by performing extra knee gain. To control the extent of the knee function, min/max knee values are introduced which control the range in which g_k can change. Hence, images are not drastically changed.

An example of such a control is realized by modifying g_k to achieve that $Med = a * Avg$, ($a<1$). The setting of a depends on the input image and user preferences. When designing such a control, one has to anticipate on the change of the image histogram that occurs as a result of the gamma transfer function, and to pre-compensate for it. The parameter that controls the extent of the gamma function (g_g) is implementation dependent. We can create versatility of the gamma functions from the linear one to those that are much steeper than the standard gamma function (x and y are input and output signals, respectively):

$$y = x^{g_g}, \text{ where } g_g \in [0.2,..,1]. \tag{2}$$

We calculate the *Med* value from the differentiated image histogram after the knee transfer function. Namely, we only consider pixels that belong to the detailed regions in the image. A simple implementation of this action is to start at the beginning of each line and to consider only pixels which are different from the previously selected pixel for a given threshold. Hence we ensure that expansion of the dynamic range occurs only if there are visually interesting details in the darker image parts. Multiple-exposure time sensor technique provides us with a better SNR and enables a low-noise output image even when significant black stretching is performed.

The median is chosen as a control measurement since it is a simple central tendency description of pixel distribution in the image histogram. Instead of the median, we could also use other percentile measurements or other kinds of measurements like mode, skewness or kurtosis. The guideline is to measure where the majority of pixels is, how many low luminance pixels are left after $f_{knee}(x)$ and how many high luminance pixels are compressed due to the overall transfer function.

Figure 5: Results: (a) standard camera image, (b) smart extended range Gamma, (c) method from the Ref. [3], (d) our method (a=0.5).

III. RESULTS AND CONCLUSIONS

We have tested our HDR expansion scheme and compared it to other approaches, using both low dynamic-range (LDR) and HDR video sequences. One can observe loss of details either in dark or bright areas when using the other methods, and our clear improvement of dark objects while keeping a good gradation in bright areas, as in Fig. 5. For other scenarios, similar improvement results are obtained. In cases when the input image has LDR, no extra black stretching occurs, which is then advantageous for the image contrast. Otherwise, for HDR images it performs the black stretch depending on the image parameters and user preferences. It is beyond discussion that the presented technique is attractive for both consumer cameras (camcorders, etc.) and professional equipment. However, the tuning should be adapted to the application. Also, with newer sensors with better SNR in dark areas, the applicability of our technique is more beneficial.

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