The intrinsic error of exposure fusion for HDR imaging, and a way to reduce it

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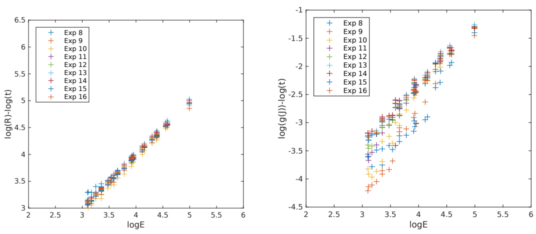
Human visual system is capable to capture details in dark and bright areas at the same time despite the dynamic range of the scene. Digital cameras, however, have a limited dynamic range, therefore only capturing dark or bright areas in a single shot. Considering that, Mann and Picard [6] presented a method for the creation of high dynamic range (HDR) radiance map by exposure fusion of a stack of low dynamic range (LDR) images. There is a wide range of HDR literature: assuming static scenes and no camera motions [2, 6], considering motion on camera and/or in the scene [4], and most recently video creation [5].

Camera sensor provides the irradiance, RAW values (which are proportional to the radiance scene), but then cameras apply linear and non-linear transformations, and a quantization step are applied resulting in a non-RAW image (such as JPEG). All approaches based on exposure fusion applied on these non-RAW images share a set of assumptions: 1) different color channels are independent, 2) in-camera non-linear correction curves are monotonic and smooth, but arbitrary in shape, and 3) the camera response function (CRF) remains constant while changing the exposure. Our work shows that these assumptions are not preserved when working with non-RAW formats, because camera may introduce changes from one exposure to the next. Thus, the exposure fusion of non-linear images will introduce more error in the final HDR radiance map, than computing it directly from RAW linear data.



(a) (b)

Figure 1: Plots computed for points in the colored squares in the dark color checker in *LuxoDoubleChecker* scene from Fairchild dataset [3], using (a) the RAW values, and (b) the JPEG values. While in both cases the plots should theoretically be a single line of slope one, it can be seen that in the JPEG case the points are more dispersed than in the RAW case.

Our algorithm follows the approach in [8, 9], which performs color stabilization based on camera color processing pipeline described in [1]. A set of LDR images with different exposure times are acquired $I_j,\ j = 1,\dots,N$ of the same HDR static scene. From these input images, we first select the best exposed image $I_{N'}$ as the one with less over and under-exposed pixels. For one-to-one pixel correspondences we perform image registration, then for each $(I_j,\ I_{N'})$ pair we undo the gamma correction and finally we compute the color correction matrix H_j that transforms colors from gamma corrected I_j to gamma corrected $I_{N'}$. In the end, we obtain the new transformed linear I'_j images.

Algorithm 1 HDR radiance map generation

Input: set of N images
Result: *HDR* radiance map
1. Select the best exposed image $I_{N'}$,
2. Register the images,
3. For each pair $(I_j,\ I_{N'}),\ j = 1,\dots,P$, [8]:
  3.1. Undo γ_j correction, and
  3.2. Estimate H_j color correction matrix.
4. Average the new linear images $I'_j = H_j \cdot I_j^{1/\gamma_j}$.

In order to evaluate our results, we use the Fairchild dataset [3] which provides linear data (RAW), and its correspondent non-linear data (JPEG). A ground truth (GT) is created using the linear data, thus we computed the PSNR of Debevec and Malik results, because most of recent methods follow its same assumptions, and our approach with the GT. In table 1, we show that in terms of PSNR our method improves the average by $\sim$ 2dB. We present qualitative results in Fig. 2, where our results are more contrast, and therefore, more details are perceived.

Figure 2: HDR results (tone mapped with [7]) obtained with the method of Debevec and Malik (1st row) and with our approach (2nd row).

Table 1: PSNR on the color channels (R,G,B) and the luminance channel (L), for the method of Devebec and Malik [2] and the proposed method.

	$PSNR_R$	$PSNR_G$	$PSNR_B$	$PSNR_L$
Devebec and Malik [2]	25.70	26.15	26.80	26.30
Proposed	**28.47**	**28.73**	**28.37**	**28.86**

In conclusion, we present an algorithm to obtain an HDR map from a set of LDR images which is based upon the digital camera imaging pipeline, and useful when working with non-linear data as JPEG. Results show that our algorithm quantitatively outperforms the work of Debevec and Malik in most of the cases considered.

[1] S. Bianco, A. Bruna, F. Naccari, and R. Schettini. Color space transformations for digital photography exploiting information about the illuminant estimation process. *JOSA A*, 29(3):374–384, 2012.

[2] P. E. Debevec and J. Malik. Recovering High Dynamic Range Radiance Maps from Photographs. In *Proceedings of the 24th Annual Conference on Computer Graphics and Interactive Techniques*, SIGGRAPH '97, pages 369–378, New York, NY, USA, 1997.

[3] M. D Fairchild. The HDR photographic survey. *Color and Imaging Conference*, 2007(1):233–238, 2007.

[4] J. Hu, O. Gallo, K. Pulli, and X. Sun. HDR Deghosting: How to deal with Saturation ? In *CVPR*, 2013.

[5] J. Kronander, S. Gustavson, and J. Unger. Real-time HDR Video Reconstruction for Multi-sensor Systems. In *ACM SIGGRAPH 2012 Posters*, SIGGRAPH '12, pages 65:1–65:1, New York, NY, USA, 2012. ACM.

[6] S. Mann and R. W. Picard. On Being 'undigital' With Digital Cameras: Extending Dynamic Range By Combining Differently Exposed Pictures. In *Proceedings of IS&T*, pages 442–448, 1995.

[7] E. Reinhard, M. Stark, P. Shirley, and J. Ferwerda. Photographic tone reproduction for digital images. *ACM Trans. Graph.*, 21(3):267–276, July 2002.

[8] J. Vazquez-Corral and M. Bertalmío. Color Stabilization Along Time and Across Shots of the Same Scene, for One or Several Cameras of Unknown Specifications. *Image Processing, IEEE Transactions on*, 23(10):4564–4575, Oct 2014.

[9] J. Vazquez-Corral and M. Bertalmío. Simultaneous blind gamma estimation. *IEEE Signal Process. Lett.*, 22(9):1316–1320, 2015.