Inverse Tone Mapping High Dynamic Range Images

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***Abstract*—HDR (High Dynamic Range) imaging is an area of increasing importance but most display devices still has LDR (Limited Dynamic Range). While retaining important visual information, various techniques have been proposed for compressing the dynamic range. When used for range compression, multi-scale image processing techniques widely used for many image processing tasks have a reputation of causing halo artifacts. However, they can work when properly implemented as demonstrated. A symmetrical analysis-synthesis filter bank is used and a local gain control is applied to the sub-bands. As also shown, the technique can be adapted for the related problem of inverse tone mapping in which a HDR image is converted to a LDR image and later expanded back to HDR image.**

Keywords—high dynamic range; tone mapping; range compression; non-linear functions; wavelets; sub-bands; multi-scale; multi-resolution; inverse tone mapping; range expansion

I. INTRODUCTION

There has been an explosion of interest in HDR imagery [1][2] in recent years. From sources such as digital photography, computer graphics, and medical imaging, HDR image data is increasingly available [3]–[6]. The dominant display technologies such as printed paper have LDR although new HDR display systems are being developed [7]. For compressing the dynamic range of the signal so the information can be displayed effectively, the various techniques which have been therefore developed should be ideally easy to implement, should work automatically with minimal human intervention, and should also avoid introducing unpleasant artifacts.

A technique is described to retrieve a HDR image from a LDR image with minimal degradation. This technique can turn a HDR image into a LDR image, and later convert it back to a good approximation of the original HDR image. This could have many uses since a great deal of hardware and software is designed around LDR imagery. It is possible to do further data compression and still retrieve a HDR image with only modest degradations.

II. OVERVIEW

Others [8]-[10] have extensively reviewed the recent literature on range compression and the reader is referring to these sources. Compressive point non-linearity is used by the most straightforward techniques called global tone mapping methods. The original image is simply mapped to a modified image with a compressive function such as a power function or a function adapted to the image histogram [11]-[14]. The dynamic range is reduced but the contrast of details is compromised and the images can look washed out. It is necessary to use more complex techniques to compress the range while maintaining or enhancing the visibility of details. An early technique is described by Stockham who observe that an image is a product of two images: an illumination image and a reflectance image. Greatly, the illumination can vary from region to region causing the dynamic range problems. The local illumination is estimated by Stockham as a geometric mean over a patch and is divided out. This is equivalent to subtracting a blurred version of the image in the log luminance domain. When there is an abrupt change of luminance at large step edges, artifacts known as halos are introduced by the method unfortunately. The size of the halo depends on the size of the blur. To capture properties of the human visual system including some designed, multi-scale techniques [15]-[17] have reduced the visibility of the halos but have not removed them. Therefore, other approaches have been explored by the computer graphics community. Estimate the illumination level and a corresponding gain map with an edge-preserving blur is one popular approach. Thereby preventing halos, the notion is that sharp edges of the gain map should be at the same points than the original image [18][19]. Particularly good results are achieved by Durand and Dorsey who compute a gain map with the bilateral filter described by Tomasi and Manduchi. For fast computation, methods are also developed by them. As is done in Retinex algorithms [20], an alternate approach is to work in the gradient domain. Reducing large gradients relative to small ones, a gain map for the gradient of the image is computed and Poisson's equation is then solved by Fattal to retrieve an image with compressed range. After manipulating the gradient field, solving Poisson's equation can be problematic but approximations that gave visually satisfying results with reasonable computation times are developed by Fattal.

There is some patent literature that suggests their utility, although multi-scale representations have lost favor in the computer graphics community. Mallat and Zhong's wavelet method is adapted by Labaere and Vuylsteke representing signal in terms of positions and magnitudes of maxima of the outputs of edge-sensitive filters. The dynamic range can be controlled by reducing the size of the high magnitude edges. A method combining multi-scale processing with traditional tone mapping is described by Lee. An image is first run through a point non-linearity to reduce its dynamic range. The resulting image suffers from the usual reduced visibility of edges and other details. A sub-band decomposition of the original image is then computed by Lee and portions of the sub-bands are added back to the tone mapped image in order to augment the visibility of detail at various scales. To control the amount of augmentation from the sub-bands, gain maps are used. The use of several sub-band decompositions is described by Vuylsteke and Schoeters including Laplacian pyramids, wavelets, and Gabor transforms, along with sigmoid non-linearity to limit the amplitude of the sub-band signals. This approach is effective but distortions including halos can be introduced. In an effort to achieve good range compression with minimal artifacts, a set of methods with a similar structure is explored.

III. METHODOLOGY

Given that the range of an HDR image can be compressed into an LDR image, it is interesting to ask whether the process can be inverted. For instance, suppose that an HDR image have been squeezed into an LDR image. Clearly a good HDR image can not be retrieved perfectly but perhaps a good approximation can be gotten. This process will be referred as “inverse tone mapping”. Little attention appears to have been done to this problem.

HDR images are represented in various ways, including lossless and lossy standards. To increase the dynamic range [21]-[34], 8 bits format like JPEG is combined with auxiliary information (a second image) using some hybrid techniques. However, the question which has to be asked is this: can a high quality HDR image be retrieved from an LDR image without sending another image in a side channel? And further, can this be done so that the LDR image would be viewed directly on an LDR display?

For converting an HDR image to LDR, the default method is simply to divide by 16 and quantize the 4096 levels to 256 levels. The 256 levels are stretched back to the original 4096 to retrieve an HDR image. This is better done with non-linear quantization in which the original linear intensity values are compressed with, for example, a log or a power function followed by quantization. By applying the inverse function, the HDR image is retrieved. Visible quantization steps in the HDR image will lead by this method since there is only 8 bits worth of intensity levels.

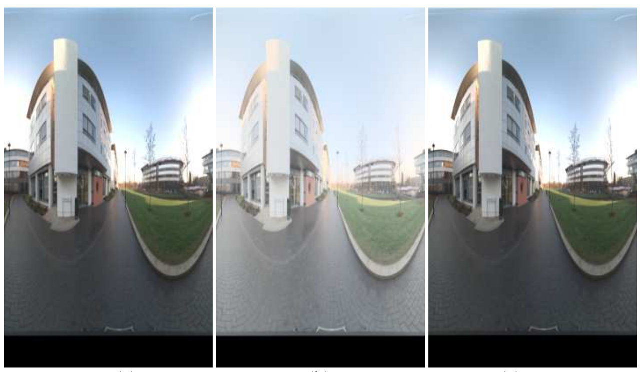
However, suppose that the HDR image is converted to an LDR image through sub-band range compression and the process is then inverted to retrieve an HDR image. Low amplitudes and high frequencies are amplified by the compression process and reduced by the expansion process (relative to the other components). Since low amplitudes and high frequencies tend to dominate quantization artifacts, this means that the artifacts will have less visibility in the expanded image than they would with ordinary quantization. One application would be in driving HDR displays. Today, only LDR images are handled by most software applications and can be put out by most video cards. It would be very useful if an LDR image could be output on our laptop and have them magically converted into a clean HDR images by a specialized display. Of course, this conversion can not be made without any loss of information but the image space can be distorted so that the accessible set of images more closely matches the ones to be displayed.

HDR image storage and transmission is another application. After an HDR image is turned into an LDR one, it can be stored in a standard lossless 8 bits format or can be further compressed with a lossy format such as JPEG which will not have the same quality as the original raw HDR image but will require much less storage space and will be in a standard format. When manipulating the captured image data, much more flexibility will be given for the user of a digital camera storing HDR JPEGs rather than standard JPEGs.

Suppose the range compression algorithm is run and an LDR image is generated. If the gain map used for each sub-band is known, the inversion process would be simple. Unfortunately, the gain maps are not known since they were not stored; only the range compressed image itself is known. The gain maps from this image can be estimate but this estimation will be imperfect so the original image will not be gotten back.

It is useful to begin at the end to solve this dilemma. For doing inverse tone mapping, a standard method is established given an LDR image expanded to an HDR image by an algorithm. This can be thought of as a decoding process. The problem now is to create an encoded image that will yield the desired image when it is decoded. There is not a method for finding this image directly but it can be searched for it using an iterative technique. In this section, the inverse tone mapping algorithm is described and an iterative method can be coupled with it.

Figure 1 and Figure 2 show examples where a tone mapping algorithm with non-linear functions is applied to compress the dynamic range of an HDR image. Inverse tone mapping is then applied to the resulting LDR image to produce a reconstructed HDR image.



(a) (b) (c)

Fig. 1. Example 1 of Inverse Tone Mapping: (a) HDR Image, (b) Resulting LDR Image, (c) Reconstructed HDR Image

The inverse tone mapping follows almost exactly the same scheme as the tone mapping does except that the sub-band coefficients are divide by their gains instead of multiplying them with their gains. The gain maps are computed in this way: an LDR image is first decomposed into sub-bands which are then rectified and blurred to give the activity maps. Gain maps are then computed from the activity maps and used to modify the sub-bands.

An HDR image is reconstructed from the modified sub-bands.

Next, given this inverse tone mapping method, an LDR image would be found in a way that, when expanded, it well approximates a target HDR image. A first thought would be to get the LDR image directly by compressing the range of the HDR image using sub-band decomposition and automatic gain control. Gain maps are computed from the sub-bands of the HDR image and multiplied with the sub-bands. If the transforms are orthogonal and somehow magically gain maps are equal then the reconstructed HDR image can be equal to the original HDR image by doing the inverse tone mapping. This will not occur because gain maps can not be the same since one is estimated from the sub-bands of the LDR image and the other from the sub-bands of the HDR image. But these will be close as the sub-bands of the LDR image and those of the HDR image are highly correlated which makes gain maps highly correlated. If the reconstructed HDR image and the original HDR image differ then a signal is added to the LDR image in order to reduce the error between the reconstructed HDR image and the original HDR image. This is done iteratively until a satisfactory result is found.

(a) (b) (c)

Fig. 2. Example 2 of Inverse Tone Mapping: (a) HDR Image, (b) Resulting LDR Image, (c) Reconstructed HDR Image

The error feedback search is started by computing the initial estimate, as the LDR version of the original image, which is then quantized and passed through the inverse tone mapping box. The reconstruction error is feed back into the loop and estimate is improved. The difference between the reconstructed image and the original image is computed, this error image is run through tone mapping, and this compressed error is added back to the previous quantized estimate. To get the updated estimate, the resulting image is then quantized. This process is repeated. In this experience, satisfactory results are reached after multiple runs and the process is not much affected by the choice of parameters but the same set of parameters will have to be used by tone mapping and inverse tone mapping which means the parameters should be sent as header information with the LDR image.

The LDR image is found iteratively but the procedure for inverse tone mapping it to HDR is a one-shot multi-scale procedure. Note that in the above iterations, taking the log of the image intensities is not included in the tone mapping and inverse tone mapping boxes. The inverse tone mapping is assumed to be applied in the log domain for HDR images that is to say the original image has gone through a log transformation before going into the loop.

Figure 3 shows the flowchart of the proposed system.

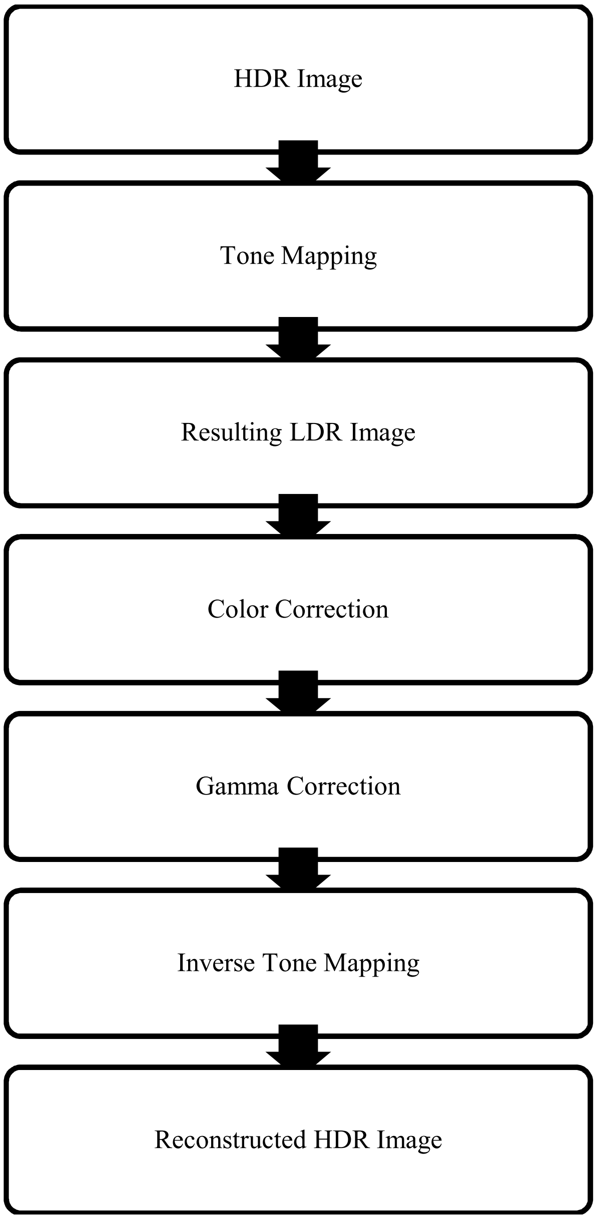


Fig. 3. Flowchart

RGB is first converted to the HSV space for inverse tone mapping color images. The value V is then run through the inverse tone mapping loop and, when the iterations stop, a compressed V is obtained and combined with the original hue H while the original saturation is divided by a factor and converted back to RGB to get the compressed color image. This is the same process for color HDR image compression. When the inverse tone mapping is going to be applied to a compressed color image, the one-step is similarly done on its V channel. The saturation is multiplied by the same factor, the hue is kept the same, and they are combined with the V channel to get the HDR color image back.

IV. CONCLUSION

For compressing HDR images in such a way that they are viewable on ordinary displays, there are a number of techniques. Multi-scale techniques have the reputation of being difficult to use without introducing halo artifacts. However, good range compression without disturbing halos is given by the implementation, based on analysis-synthesis sub-band architectures and smooth gain control, described in this paper. Some simple implementations of sub-band range compression are described and the results shown are competitive with the leading techniques such as Durand and Dorsey, Reinhard, and Fattal.

Optimized code has not been written and speed cannot be compared with the other techniques. However, the filtering operations involved are simple to compute and there is no need to use large or complex filters. It is likely that in the future hardware wavelet processing will be common in image processing systems and it will be straightforward to utilize this hardware for range compression.

This compression scheme can be inverted so that a LDR image can be expanded into a HDR image. Given an original HDR image, a LDR image can be computed offering a good visual rendition of the HDR image which can be expanded to approximate the original HDR image with minimal degradation. For example, this could be useful to drive both LDR and HDR display when using a standard video card. For backward compatibility in various systems, the ability to represent HDR images in LDR file formats is also an advantage and can lead to further savings in storage when combined with JPEG compression.

REFERENCES

[1] M. A. Touil and N. Ellouze, “Secure High Dynamic Range Images”, International Journal of Advanced Computer Science and Applications (IJACSA), vol.7(4), no. 18, 2016.

[2] M. A. Touil and N. Ellouze, “Scrambling High Dynamic Range Videos”, Future Technologies Conference, San Francisco, 2016.

[3] E. H. Adelson, E. Simoncelli, and R. Hingorani, “Orthogonal Pyramid Transforms for Image Coding”, in Visual Communications and Image Processing II, Proceedings of the SPIE, vol. 845, 50–58, 1987.

[4] P. E., Debevec and J. Malik, “Recovering High Dynamic Range Radiance Maps from Photographs”, in Proceedings of SIGGRAPH 97, Computer Graphics Proceedings, Annual Conference Series, 369–378, 1997.

[5] K., Devlin, A. Chalmers, A. Wilkie, and W. Purgathofer, “Star: Tone Reproduction and Physically Based Spectral Rendering”, in State of the Art Reports, Eurographics (September), 101–123, 2002.

[6] J. M. Dicarlo and B. A. Wandell, “Rendering High Dynamic Range Images”, in Proceedings of the SPIE: Image Sensors, vol. 3965, 392–401, 2001.

[7] F. Durand and J. Dorsey, “Fast Bilateral Filtering for the Display of High Dynamic Range Images”, ACM Transactions on Graphics 21, 3 (July), 257–266, 2002.

[8] R. Fattal, D. Lischinski, and M. Werman, “Gradient Domain High Dynamic Range Compression”, ACM Transactions on Graphics 21, 3 (July), 249–256, 2002.

[9] J. A. Ferwerda, S. Pattanaik, P. S. Shirley, and D. P. Greenberg, “a Model of Visual Adaptation for Realistic Image Synthesis”, in Proceedings of SIGGRAPH 96, Computer Graphics Proceedings, Annual Conference Series, 249–258, 1996.

[10] D. J. Heeger, “Half-Squaring in Responses of Cat Simple Cells”, Visual Neurosci, 9, 427–443, 1992.

[11] IJG, Independent Jpeg Group, http://www.ijg.org/files/.

[12] D. J. Jobson, Z. Rahman, and G. A. Woodell, “a Multi-Scale Retinex for Bridging the Gap between Color Images and the Human Observation of Scenes”, IEEE Transactions on Image Processing 6, 7 (July), 965–976, 1997.

[13] F. Labaere and P. Vuylsteke, “Image Contrast Enhancing Method”, U.S. Patent 5, 717, 791, 1998.

[14] E. H. Land and J. J. Mccann, “Lightness and Retinex Theory”, Journal of the Optical Society of America 61, 1 (January), 1–11, 1971.

[15] G. W. Larson, H. Rushmeier, and C. Piatko, “a Visibility Matching Tone Reproduction Operator for High Dynamic Range Scenes”, IEEE Transactions on Visualization and Computer Graphics 3, 4, 291–306, 1997.

[16] H. C. Lee, “Automatic Tone Adjustment by Contrast Gain-Control on Edges”, U. S. Patent 6, 285, 798, September, 2001.

[17] S. Mallat and S. Zhong, “Characterization of Signals from Multi-Scale Edges”, IEEE Transactions on PAMI 14, 7, 710–732, 1992.

[18] S. Mallat, “a Wavelet Tour of Signal Processing”, New York: Academic, 1998.

[19] S. Mann and R. Picard, “Being ‘Undigital’ with Digital Cameras: Extending Dynamic Range by Combining Differently Exposed Pictures”, in IS&T’s 48th annual conference, 422–428, 1995.

[20] T. Mitsunaga and S. K. Nayar, “High Dynamic Range Imaging: Spatially Varying pixel Exposures”, in IEEE CVPR, 472-479, 2000.

[21] Nakazawa, Masayuki, Tsuchino, and Hisanori, “Method of Compressing a Dynamic Range for a Radiation Image”, U. S. Patent 5, 471, 987, 1995.

[22] S. N. Pattanaik, J. A. Ferwerda, M. D. Fairchild, and D. P. Greenberg, “a Multi-Scale Model of Adaptation and Spatial Vision for Realistic Image Display”, in Proceedings of SIGGRAPH 98, Computer Graphics Proceedings, Annual Conference Series, 287–298, 1998.

[23] E. Peli, “Contrast in Complex Images”, J. Opt. Soc. Am. A. 7, 10, 2032–2040, 1990.

[24] E. Reinhard and K. Devlin, “Dynamic Range Reduction Inspired by Photoreceptor Physiology”, IEEE Transactions on Visualization and Computer Graphics, 2005.

[25] E. Reinhard, M. Stark, P. Shirley, and J. Ferwerda, “Photographic Tone Reproduction for Digital Images”, ACM Transactions on Graphics 21, 3 (July), 267–276, 2002.

[26] H. Seetzen, W. Heidrich, W. Stuerzlinger, G. Ward, L. Whitehead, M. Trentacoste, A. Ghosh, and A. Vorozcovs, “High Dynamic Range Display Systems”, ACM Transactions on Graphics 23, 3 (August), 760–768, 2004.

[27] T. Stockham, “Image Processing in the Context of a Visual Model”, Proc. IEEE 60, 828–842, 1972.

[28] C. Tomasi and R. Manduchi, “Bilateral Filtering for Gray and Color Images”, in Proc. IEEE Int. Conf. on Computer Vision, 836–846, 1998.

[29] J. Tumblin and H. E. Rushmeier, “Tone Reproduction for Realistic Images”, IEEE Computer Graphics & Applications 13, 6 (Nov.), 42–48, 1993.

[30] J. Tumblin and G. Turk, “Lcis: a Boundary Hierarchy for Detail-Preserving Contrast Reduction”, in Proceedings of SIGGRAPH 99, Computer Graphics Proceedings, Annual Conference Series, 83–90, 1999.

[31] J. Tumblin, “Three Methods of Detail-Preserving Contrast Reduction for Displayed Images”, PhD Thesis, College of Computing Georgia Inst. of Technology, 1999.

[32] P. Vuylsteke and E. Schoeters, “Method and Apparatus for Contrast Enhancement”, U.S. Patent 5, 805, 721, 1998.

[33] G. Ward and M. Simmons, “Sub-band Encoding of High Dynamic Range Imagery”, in APGV ’04: Proceedings of the 1st Symposium on Applied perception in graphics and visualization, ACM Press, 83–90, 2004.

[34] G. J. Ward, “the Radiance Lighting Simulation and Rendering System”, in Proceedings of SIGGRAPH 94, Computer Graphics Proceedings, Annual Conference Series, 459–472, 1994.