Automatic Selection of Brackets for HDR Image Creation

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Abstract

High Dynamic Range imaging (HDR) is now readily available on mobile devices such as smart phones and compact cameras. To produce HDR images, these devices take several pictures of the same scene using different exposure settings. The more the pictures, the better the HDR image quality, but also the heavier the computation load required to compensate for camera and object movements. A trade-off between quality and computational complexity must therefore be selected. Currently, smart phones and compact digital cameras take two to three pictures, or "brackets". Due to the smaller number of brackets used and processor speed limitations, the quality of HDR images produced by mobile devices is not up to par with HDR images generated by the state of the art algorithms implemented on desktop computers.

Here, we describe an algorithm that can select a subset of brackets, from a larger set, that maximizes the amount of dynamic range information available at every pixel. This enables devices with limited computational power to use a smaller number of brackets, thereby limiting the computational requirements, while at the same time having enough dynamic range information to ensure good HDR creation quality.

1 Introduction

General interest in High Dynamic Range imaging (HDR) has considerably increased in the past years, thanks to a number of recently proposed HDR creation algorithms [1-6]. HDR imaging techniques significantly enhance image quality compared to standard photography: HDR images do not suffer from over or under-exposed regions, reveal more details in the shadow and the highlighted areas, and reflect more accurately the perceptual experience a person would have if truly viewing the photographed scene. Current HDR implementations generally involve taking several pictures (or "brackets") of the same scene, typically two to seven, with different exposure settings. HDR creation algorithms take advantage of the larger dynamic range captured by the multiple brackets, and combine their information to generate the HDR image [1]. An important assumption of the bracket combination stage is that corresponding pixels in different brackets are perfectly aligned, and correspond to the same objects. However, general scenes are not static: the camera or objects in the scene may move while the set of brackets is being taken. Therefore, additional computations are necessary, in particular when using hand-held devices, to compensate for these movements [2-6]. The bulk of the computational load in HDR image creation stems from the movement compensation algorithms; this forms a limiting factor in the quality of HDR images delivered by current mobile devices and compact cameras [2].

To reduce the computational load during creation of HDR images, we propose a bracket selection stage that selects a subset of brackets from a larger set, significantly reducing the required processing for compensation of camera and object movements. Reducing the number of brackets used runs the risk of losing useful dynamic range. However, if the brackets are chosen specifically to optimize the dynamic

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range information available, it is likely the information in the selected subset will be sufficient to create high quality HDR images.

Here, we propose a simple, fast and effective algorithm to select an optimal subset of brackets from a larger set. The algorithm uses an exposure quality measure to explicitly maximize the information available in the subset of brackets. A number of methods have previously been used to select a single reference bracket in the context of HDR image creation and artifact removal [5-6] but, up to our knowledge, no method has been proposed to explicitly select an optimal subset of multiple brackets. Figure 1 illustrates where our bracket selection algorithm fits into the HDR image creation flow.

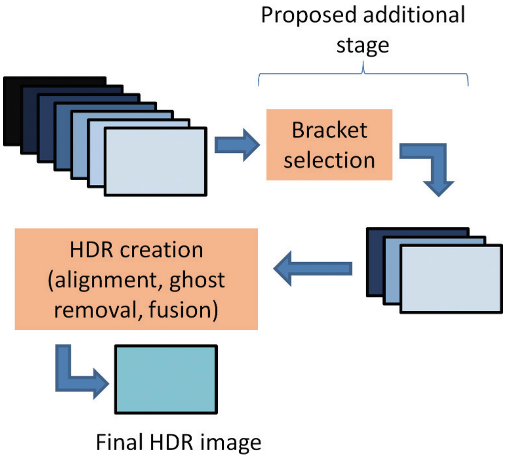

Fig. 1 Proposed HDR creation process flow. The bracket selection takes place right after the brackets have been taken. Standard HDR creation flow proceeds thereafter. Using a reduced but appropriate subset of brackets significantly decreases the HDR creation computational overhead required by alignment of images and ghost artifact removal.

In the next section, we describe the bracket selection algorithm. In the section that follows, we illustrate the algorithm on an example set of image brackets. We then discuss the robustness of the algorithm to misalignments and finally provide a discussion and a conclusion.

2 Bracket selection algorithm

Given a set of N brackets, we aim to select a subset of $n < N$ brackets with maximal dynamic range information. There will be $\binom{N}{n}$ such n-tuples. For example, if we want to select 3 brackets from a total of 7, there will be 35 different 3-tuples ("triplets") of brackets. The algorithm will choose the particular triplet, among the possible 35, that is likely to yield the highest quality HDR image if only 3 bracket can be used.

The algorithm is as follows. We first compute the "exposure-quality" of every pixel, in each bracket. Denote by I_i^j the gray-level intensity value of pixel i in bracket j, $1 \leq j \leq N$. The exposure quality q_i^j of this pixel is obtained by applying a mapping function f: $[0,\ldots255] \rightarrow [0\ 1]$ that gives high values to pixels whose exposure is reliable, i.e. towards the center of the range [0,...255], as the weighting function in [1]:

$$q_i^j = f(I_i^j) \tag{1}$$

Examples of possible functions to use are given in Figure 2. Applying f to all pixels of each bracket yields N different exposure quality maps q^j, as illustrated in Figure 3. The particular function can depend on the camera or sensor model, but the function will typically have low value for the extreme intensities and high values for the central ones.

Once the exposure quality map is computed for each bracket, we generate a tuple-specific quality map Q^k, for each possible n-tuple. k is the index of the tuple in the set of possible tuples, e.g. if N=7 and n=3, then $1 \leq k \leq 35$. Let S^k represent the set of bracket indexes that belong to tuple k. For example, we could have $S^3 = \{1, 2, 5\}$, meaning S^3 represents the bracket tuple containing bracket numbers 1, 2 and 5. The value Q_i^k of Q^k at every pixel i is then computed as follows:

$$Q_i^k = \max_{j \in S^k} q_i^j \tag{2}$$

Finally, each tuple k receives a quality score m^k, which is the mean, over all pixels, of Q^k:

$$m^k = \frac{1}{M} \sum_i Q_i^k \tag{3}$$

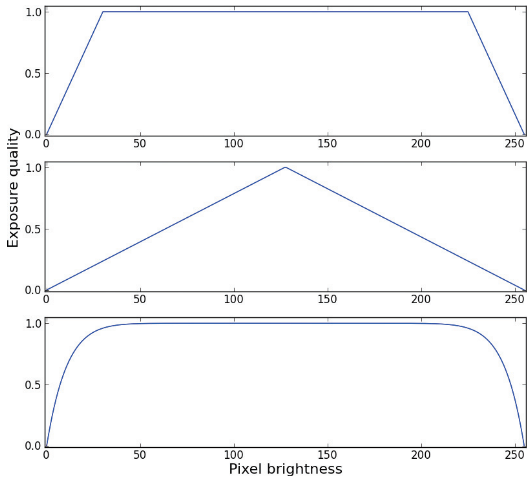

Fig. 2 Three examples of exposure quality mapping functions f.

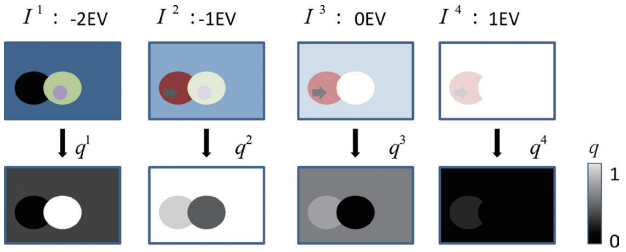

Fig. 3 Illustration of exposure-quality map computation. Top row: A simple scene is photographed with different exposure settings (EV values). Brackets with low EV values capture accurately bright scene areas, while the brackets with high EV capture areas that are dark. Bottom row: application of the mapping function *f* to each bracket (eq. 1), yielding individual exposure quality maps q^j. Very dark or very bright areas in the images (top row) lead to low exposure quality values (dark areas in bottom row).

M is the number of pixels in the image. For each pixel, Q_i^k indicates the best exposure received by pixel i among the brackets in tuple k. Using the Max operation in eq. 2 reflects whether at least one of the brackets is well exposed for a particular pixel. The tuple of brackets that is finally selected is the one with highest score m^k. This process is illustrated in Figures 4 and 5.

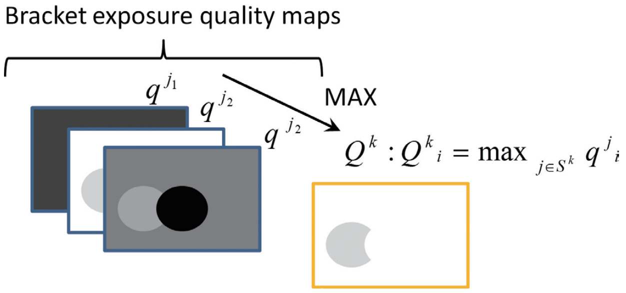

Fig. 4 Computation of the tuple specific quality map. The quality map of brackets belonging to a specific tuple are combined pixel-wise with a Max operation over the different brackets.

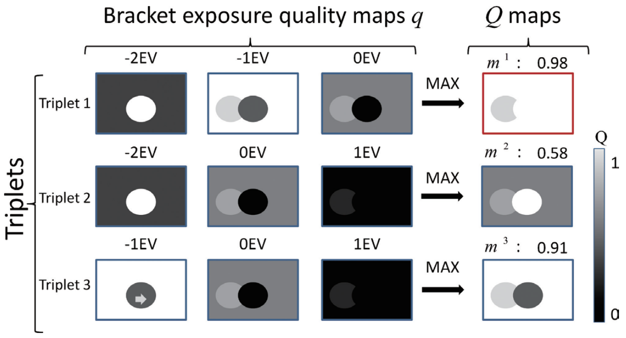

Fig. 5 Example of exposure score computation for bracket triplets (*n*=3). Quality maps of the brackets are combined with the Max operation for each triplet, leading to the *Q* maps. Each *Q* map is averaged, yielding the final score *m* for the triplet. The triplet with highest score is selected (here, 0.98). The process is similar for tuples of any size $n < N$. In this particular example, the first triplet is finally selected because it obtained the highest score *m*.

Summary of the algorithm:

1. Compute exposure quality maps q^j for all N brackets: Equation 1 and Figure 3.
2. For each tuple k:
   2.1 Compute tuple specific quality maps Q^k by combining the q^j maps of the tuple: Equation 2 and Figure 4.
   2.2 Compute the score m^k for the tuple: Equation 3.
3. Select tuple with highest m^k: Figure 5.

3 Application example

An implementation scenario of our algorithm would be as follows. The camera would shoot seven brackets with different exposure settings (instead of the standard two or three), apply the bracket selection algorithm to extract the most useful n-tuple (e.g. $n=3$), and then perform the rest of the HDR generation steps. In this manner, we obtain an HDR image making use of a large amount of dynamic range information while retaining the computational complexity of HDR creation from a smaller number of brackets, plus the small overhead for shooting and selecting the brackets. This leads to a significant improvement in performance over having to process all the seven brackets, and an improvement in quality over the standard “shoot 3” brackets with steps of 2 EV. A demonstration on a set of brackets is described below and illustrated in Figures 6 to 9.

Figure 6 shows seven brackets ($N=7$) of a scene with a high dynamic range, taken using different exposure settings. In this example, a subset of three brackets is to be selected ($n=3$) for HDR creation. We tested two different subsets. The first subset of brackets used the -2, 0 and +2 EV settings, commonly used in compact cameras or mobile devices. These settings correspond to brackets 2, 4 and 6 in Figure 6. The second subset of three brackets tested was the subset chosen by the selection algorithm proposed here. In this particular case, the algorithm selected brackets 1, 4 and 7, corresponding to EV values -3, 0 and 3. We used the Photomatix commercial software package to create and compare the HDR images obtained using both of these subsets. HDR image creation with Photomatix applied image alignment, followed by the HDR image creation steps. Results are shown in Figures 7 and 8, for the subset selected by our method and the standard 2-step difference set of brackets, respectively. In Figure 8, we note that significant details inside the light box are lost, such as the white square. These details are not lost in the

HDR image created using the triplet selected by our method. This demonstrates that the brackets chosen by the bracket selection algorithm contain more dynamic range information than the standard -2, 0 +2 EV stop brackets.

In Figure 9, we show the HDR image created using all 7 brackets. We see that this image is comparable in quality to the HDR image created from 3 selected brackets and contains the same dynamic range (Fig. 7). However, the creation time using seven brackets, including the alignment procedure, was 9s on a 64b 6.00GHz Windows computer. In contrast, the total time for HDR image creation using the bracket selection algorithm was 6s, including 1 second for the bracket selection and another 5 seconds for alignment and HDR creation. This corresponds to a 30% improvement in computational time, while retaining same image quality.

4 Robustness to movement

In HDR image creation algorithms, correct alignment of pixels is critical to avoid blurred or ghosted areas [2-6]. The algorithm we propose here is robust to the common misalignments that occur when shooting multiple brackets. Usually, corresponding areas with same exposure quality will largely overlap in brackets destined to create HDR images. The areas that do not overlap will therefore only account for a relatively small error in the quality score computed from equation 3. Therefore, the algorithm can be appropriately applied prior to alignment procedures, since misalignments do not significantly affect the tuple scores.

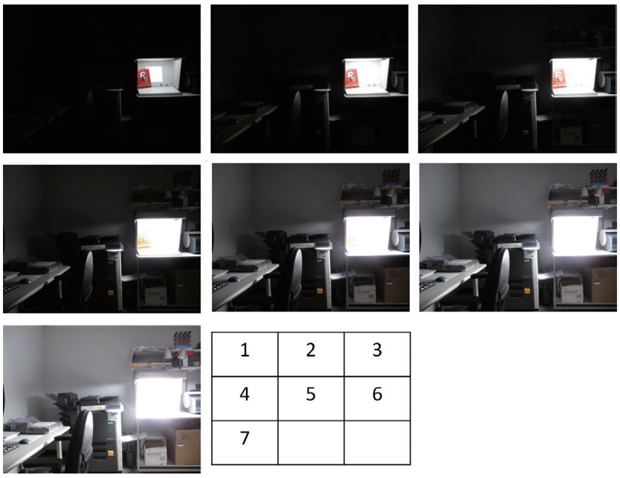

Fig. 6 Seven brackets of a scene with a high dynamic range taken with different exposure settings. Image exposure values: 1: -3EV, 2: -2EV and so on up to 3EV.

Fig. 7 HDR image created from three brackets chosen by the bracket selection algorithm (brackets 1, 4 and 7).

Fig. 8 Image created using three brackets with standard 2 stop difference (brackets 2, 4 and 6). Important details inside the light-box, such as the white square are lost using these brackets.

Fig. 9 HDR created using all 7 brackets. We notice that the same dynamic range is captured when using 3 brackets selected by our method.

5 Discussion and conclusion

We proposed an algorithm that selects an optimal subset of brackets in order to reduce computational load of HDR creation algorithms. The algorithm relies on simple computations and its complexity is linear in the number of pixels in the images. The algorithm is fast, and can be accelerated further by working on reduced image sizes, without loss of bracket selection quality.

We illustrated our algorithm with an example, showing that: 1) the selected brackets yield better results than the common method of choosing brackets with 2 exposure step differences, 2) in the application example, HDR quality was as good using the selected set of 3 brackets or the full set of 7 brackets, and 3) a significant improvement in performance was achieved (30%).

The algorithm can be modified appropriately for specific camera or sensor models, for example by using different mapping functions (f in Equation 1), or modified combination schemes (Equation 2). For example, appropriate weighting functions, taking into account spatial location of pixels, may be used in equations 2 and 3. The Max operation can also be substituted for a more appropriate function, such as Mean, if deemed necessary.

Finally, the bracket selection algorithm that we proposed is independent of the particular method used to create the HDR images, and can benefit most of the current approaches to HDR image creation. Bracket selection is to be performed right after the brackets are shot. The selected brackets are then used as input to the preferred HDR creation algorithm.

6 References

[1] 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, p. 369-378, 1997

[2] J. Hu, O. Gallo and K. Pulli, “Exposure Stacks for Live Scenes with Hand-held Cameras,” Proceedings of the European Conference on Computer Vision, 2012

[3] G. Ward, “Fast, Robust Image Registration for Compositing High Dynamic Range Photographs from Handheld Exposures,” Journal of Graphic Tools, p. 17-30, 2003

[4] A. Srikantha and D. Sidibé, “Ghost detection and removal for high dynamic range images: Recent advances,” Image Communication , Volume 27 Issue 6, 2012

[5] P. Sen, N. K. Kalantri, M. Yaesoubi, D. B. Goldman and E. Shechtman, “Robust Patch-Based HDR Reconstruction of Dynamic Scenes,” Proceedings of ACM SIGGRAPH Asia, 2012

[6] Y. Seok Heo, K. M. Lee, S. Uk. Lee,Y. Moon, J. Cha, “Ghost-free High Dynamic Range Imaging,” Computer Vision – ACCV 2010, Lecture Notes in Computer Science Volume 6495, p 486-500, 2011