HDR imaging – Automatic Exposure Time Estimation A novel approach

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ABSTRACT

Digital imaging of common scenes can be a very challenging task if the scene radiances present a high dynamic range (HDR). HDR imaging techniques are applied to overcome this issue. The most popular technique is based in the combination of differently exposed low dynamic range (LDR) images. However there is a lack of a robust method for determining either the amount of LDR pictures needed, or their exposure time settings, without any prior knowledge of scene content. In a recent publication, we proposed a novel method for estimating the set of exposure times (bracketing set) needed to capture the full dynamic range of HDR scenes including daylight skies. Now we extend the applicability of this method to any imaging system or application (scientific, industrial or artistic). The proposed method is adaptive to scene content and to any camera response and camera configuration (raw, jpeg, etc). Our method works on-line, since the exposure times are estimated as the capturing process is ongoing. Therefore, it requires no a-priori information about scene content. The resulting bracketing sets are minimal for the scene being captured. The user can set a tolerance for the maximum percentage of pixel population that is underexposed or saturated. We can use this method separately for each color or spectral channel. This method can thus also be used for multispectral imaging systems.

1. INTRODUCTION

The use of HDR imaging techniques converts our digital camera in a tool for measuring the relative radiance outgoing from each point of the scene, and for each color channel. This final HDR image is called HDR radiance map. In order to generate it, we need to know the relationship between camera response values and relative irradiance impinging on the sensor (which is proportional to the radiance outgoing from the scene). This relationship is represented by the camera response function (CRF), which is easily calculated as proposed by Debevec and Malik (2008).

Merging different low dynamic range (LDR) images into a HDR radiance map using the CRF, is a very well known technique widely used in many imaging fields from photography to scientific or industrial applications. However, when the captures take place, there is no method that allows us to determine either how many LDR shots are going to be needed or what exposure times to be used, without having any prior knowledge of the radiance content of the scene being captured. Authors care the most about optimizing the signal to noise ratio (SNR) of the resulting HDR radiance map, rather than controlling the number of shots and the final total exposure time. For this purpose, they assume known information about scene content before starting the capturing process, like known illuminant or radiance levels, or they assume a camera with linear CRF (Granados et al. (2010), Hirakawa and Wolfe (2010), Gallo et al. (2012)). Their bracketing set selection is based in finding an intermediate exposure time, and increasing and decreasing it for the contiguous shots a fixed number of stops (Stunpfel et al. (2004), Bilcu et al. (2008)). Other authors capture a large number of exposures, and afterwards select which ones to use for an optimal SNR reconstruction (Hassinoff et al. (2010), Gallo et al. (2012)). Only Barakat et al. (2008), proposed a method for finding minimum bracketing sets for any given camera. They studied the radiance ranges covered by their camera using every exposure time setting available on it. Afterwards, they selected only those exposure times that covered the full dynamic range of the camera with some overlap, eliminating redundant shots that do not add any new radiance range to the final HDR image. To make this method adaptive to scene content, they included a stopping condition if they found no underexposed or saturated pixels respectively. This way they are limiting their capturing possibilities to usually 4 or 5 possible exposure times, and they do not control the SNR of the resulting HDR radiance map.

In this work we extend the applicability of the proposed method from natural scenes with daylight skies to any general or particular HDR imaging application. Numerical results of a different set of HDR radiance maps generated for daylight outdoors scenes, and a comparison with the method proposed by Barakat et al. (2008), are shown and explained in Martínez et al. (2015). Here we captured a set of 24 HDR scenes including both outdoors (with and without sky) and also indoors scenes, and also both in very bright and very dim lightning conditions.

We aimed for a method that can be used for any camera, whether it is linear or not. We wanted it to be adaptive to scene content and also to work on-line, as the capturing process is ongoing, without the need of being fed with any information about the scene. We also wanted the method to be tunable. The default configuration is to find a minimum bracketing set for the given camera and scene. However this would also mean reduced SNR compared to captures with larger number of shots and longer exposure times. Therefore, the user can tune the balance between shorter captures or higher SNR levels. We also included a parameter to bound the radiance range to be captured if we are not interested in recovering the full dynamic range, neglecting the extreme low or high radiances present in the scene (deep shadows or brilliant highlights).

We compared the SNR performance of our method, using 5 different tunning conditions (AEE-A to AEE-E), against the best SNR case that our camera can achieve. The latest case is called the ground truth (GT), and it is an HDR radiance map generated using every available exposure time that our camera offers (optimal SNR case).

2. METHOD

We present here the results obtained using a consumer camera model Canon EOS 7D working in sRGB jpeg mode (non linear). Nonetheless, the method was successfully tested as well in two linear scientific cameras (monochrome Retiga 1300 and RGB Retiga 1300C working in raw mode), yielding similar results as the ones presented here (Martínez et al. (2015)).

Our Canon camera was driven from a laptop computer via USB interface. The method proposed was implemented using Matlab and worked on-line. For the generation of GT images we just captured all 55 available exposure times in the camera.

Our method uses an initial shot as starting point. It can be any exposure time, as long as the resulting LDR image has some useful pixels (neither underexposed nor saturated). A good initial exposure time is the one implemented in the auto-exposure setting of most consumer cameras. If the camera used does not implement this function, then any intermediate exposure time would work good.

Once this image is captured, we calculate its cumulative histogram. This cue will give us information of the pixel populations which were correctly exposed in this first shot. The idea of using cumulative histograms to control sensor responses to pixel populations in the scene was taken from Grossberg and Nayar (2002), who originally used it to select pixel populations for CRF estimation.

We will consider at this point two sensor response levels: low (Lo) and high (Hi). Our algorithm will consider underexposed any sensor response that is below Lo level, and saturated whatever is above Hi level. This way, the user can tune the method. If Lo and Hi levels are set very close to the extreme sensor response values (say 0 and 255 for 8 bits data), the overlap between consecutive shots will be minimal, yielding thus a minimum bracketing set as output. If otherwise the Lo and Hi levels are selected far from these extremes, then the redundancy between consecutive shots will increase and the SNR of the resulting HDR radiance map will be higher at the cost of more shots and longer total exposure time.

So if thanks to the cumulative histogram of the image, we know the sensor responses at the Lo and Hi limits (DC_{Lo} and DC_{Hi}), and we also know the CRF, and the exposure time used (ΔT_0), we can determine the relative irradiance values (E_{Lo} and E_{Hi}) for the areas of the image which lie just in the limits of the correct exposure, as shown in equation 1:

$$E_{Lo}=\frac{CRF^{-1}(DC_{Lo})}{\Delta T_0} \quad E_{Hi}=\frac{CRF^{-1}(DC_{Hi})}{\Delta T_0} \qquad (1)$$

Now the aim is to find new exposure times, that shift the sensor responses corresponding to these irradiance values, to the opposite limit (Lo or Hi) that they were found in. For this purpose now we determine that the new longer and shorter exposure times (ΔT_{longer} and $\Delta T_{shorter}$), are calculated as shown in equation 2:

$$\Delta T_{longer}=\frac{CRF^{-1}(DC_{Hi})}{CRF^{-1}(DC_{Lo})}\cdot\Delta T_0 \quad \Delta T_{shorter}=\frac{CRF^{-1}(DC_{Lo})}{CRF^{-1}(DC_{Hi})}\cdot\Delta T_0 \qquad (2)$$

When the new exposure times are estimated, the algorithm will order to the camera, to acquire new pictures using them. For the new LDR images captured, the same procedure will be followed to find longer and/or shorter exposure times if needed. The stopping condition for this process would be to check in the cumulative histograms of the new LDR images captured, if the pixel population above Hi level or below Lo level is below some threshold percentage set by the user (zero for full range).

3. RESULTS AND DISCUSSION

We captured a set of 24 indoors and outdoors HDR scenes using our method. In every scene captured, the full dynamic range was recovered successfully, except for the case of direct sunlight, like figure 1. We see all its LDR exposures and the tone-mapped version of its HDR radiance map generated. We can also see the cumulative histograms of each LDR image. In figure 2, some other HDR tone-mapped radiance maps are shown, corresponding to outdoors and indoors scenes where the irradiance levels were lower than daylight skies'.

In order to study the SNR performance of the proposed method for different tuning conditions, we created a controlled illumination indoors scene to avoid illumination changes during the experiment. This is important because during the whole capturing process we need no changes in the radiance conditions coming from the scene to happen. This is a key factor to consider the irradiance on the sensor as a constant and not as a variable. With natural illumination this radiance stability is not controllable. We generated 6 sets of 10 HDR radiance maps. 5 of them were generated using our method with different tuning conditions (AEE from A to E). The other one was generated using all available exposure times in the camera (GT).

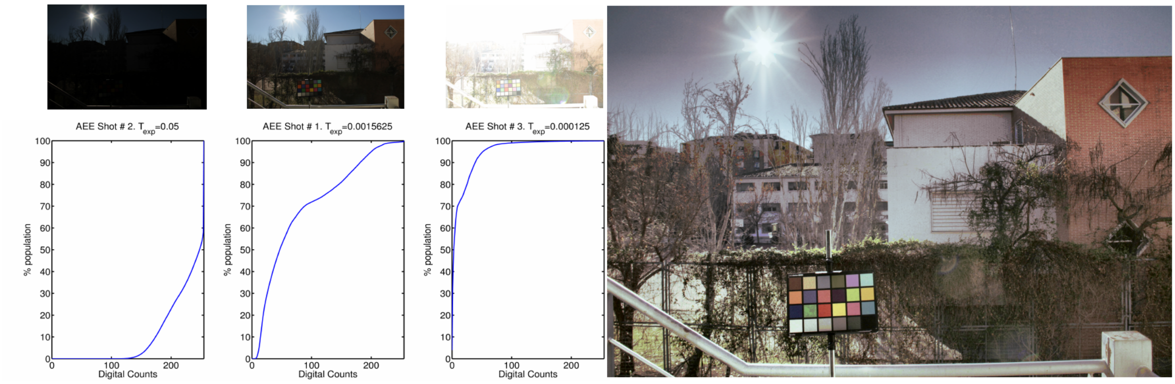

Figure 1: LDR images and histograms, and tone-mapped HDR radiance map.

Table 1. Numerical results of SNR study.

Condition	Lo level	Hi level	# of shots	ΣΔT (s)	SNR (dB)	std(SNR)
AEE A	3	252	3	8.313	23.82	2.42
AEE B	5	250	3	21.31	25.81	2.94
AEE C	10	245	3	30.2504	26.62	6.68
AEE D	30	225	4	30.252	28.14	3.45
AEE E	55	200	6	31.468	28.55	4.57
GT	X	X	55	151.4308	31.38	6.52

Numerical results are shown in table 1. We can see the total number of shots, total exposure time, average SNR and standard deviation of SNR and the Lo and Hi levels tuned.

As we can see, the minimum bracketing set achieved to recover the full dynamic range of the scene happened when setting the Lo and Hi levels close to the 8 bits sensor responses extremes. As we move these levels further from the extremes of the range, the number of shots and/or the total exposure time increase, and so does the average SNR. This is expected as for longer exposure times the signal is higher as well as because higher number of shots means to average more LDR images thus reducing the noise to a lower level.

In figure 3 we can see the HDR radiance map of the HDR indoors scene generated, as well as the SNR histograms of each of the tuning conditions tested.

Figure 2: Tone-mapped HDR radiance maps of outdoors and indoors scenes.

These results prove the ability of the proposed method to recover full range HDR radiance maps for any lightning condition, finding minimal bracketing sets, as well as the ability to control the balance between total exposure time (number of shots) and SNR. Therefore, for each application, the user can decide if faster acquisitions are more important or higher SNR are key factor, sacrificing capture speed.

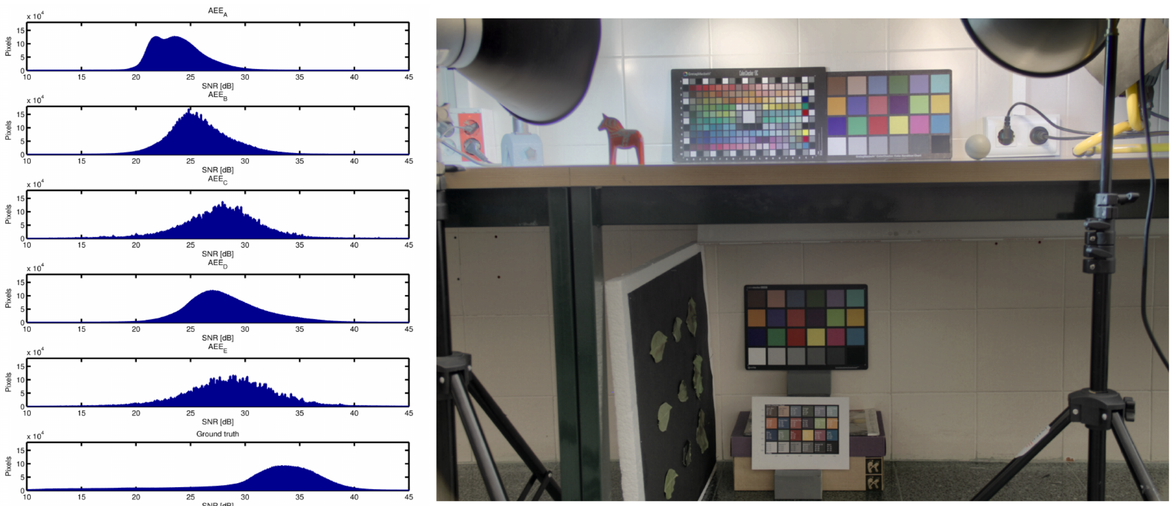

Figure 3: SNR histograms and tone-mapped HDR radiance map of indoors scene.

4. CONCLUSION

We have extended the applicability of a recently proposed method for estimating the bracketing set needed for a HDR radiance map capture via multiple LDR exposures. Our method adapts to any camera whatever camera response function has, as well as to any scene content. There is no need to know any information about scene content prior to the capture. Only a first exposure of the scene where some pixels are neither underexposed nor saturated is sufficient. We have captured several HDR scenes and in all of them the full dynamic range was covered except for direct sunlight.

We have also tested the ability of our method to be tuned in order to increase the SNR performance, at the cost of increasing also the total exposure time. We have seen how the more shots the method adds to the capture, the more similar the SNR performance is with the optimal one achievable by the camera.

The proposed method is therefore suitable for HDR imaging in any application, artistic, industrial or scientific, independently of the number of spectral channels or camera response function that the imaging system has.

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